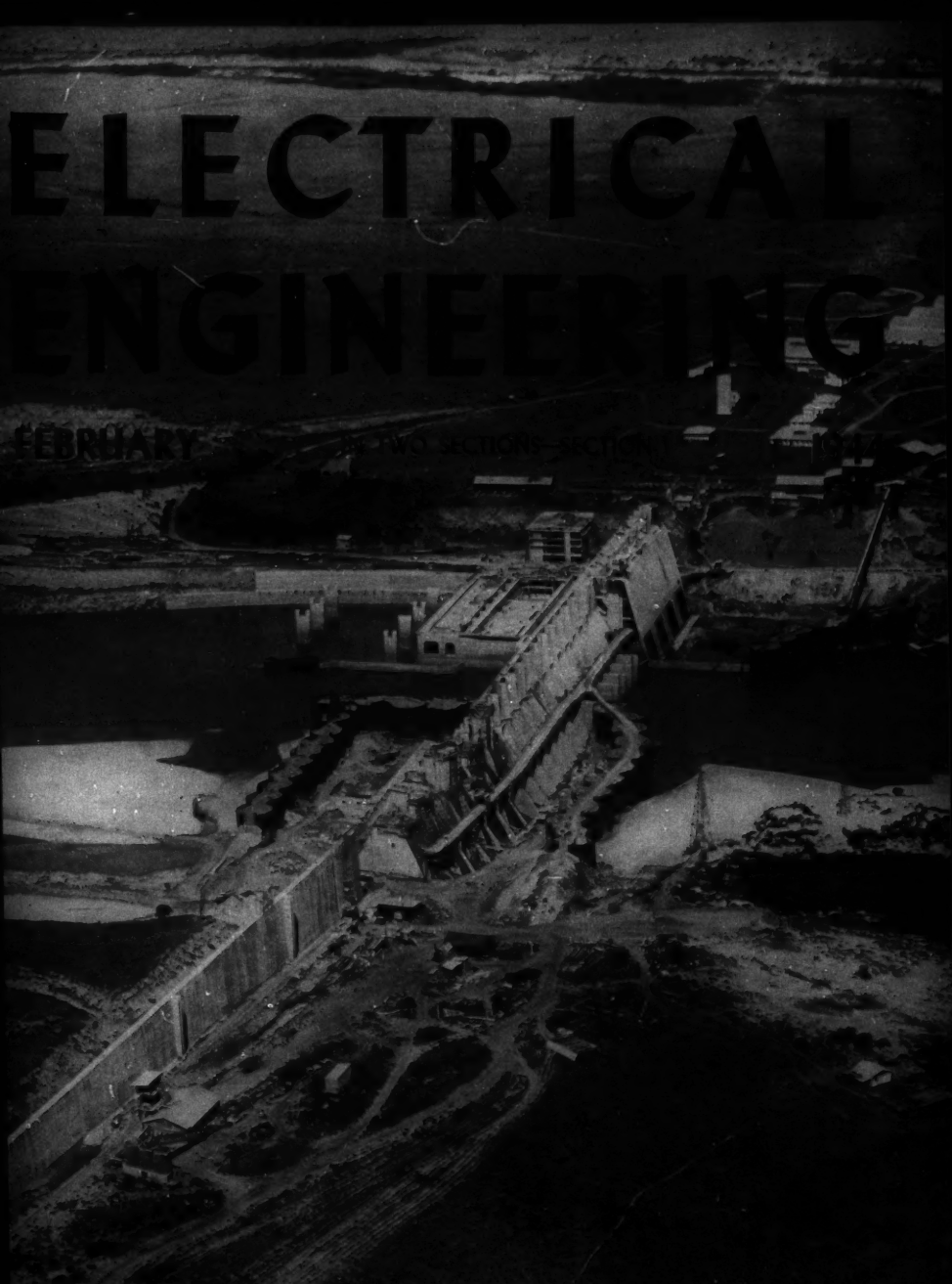
ELECTRICAL ENGINEERING

FEBRUARY TWO SECTIONS—SECTION ONE 1942



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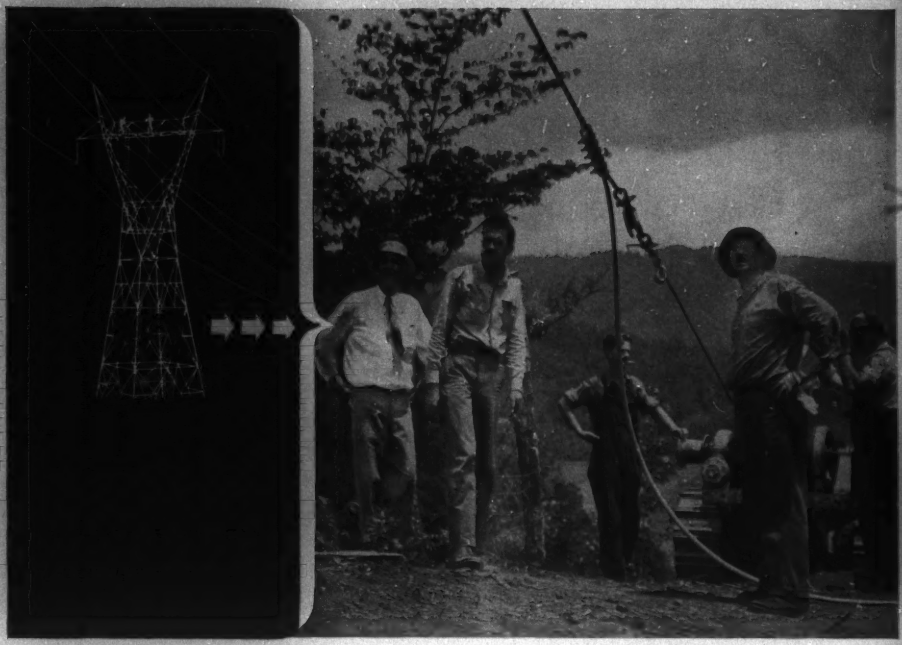

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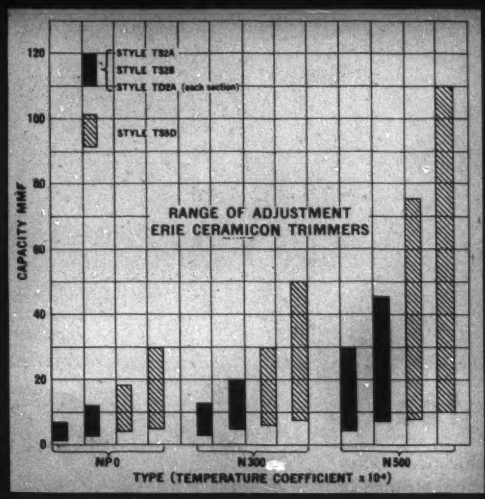

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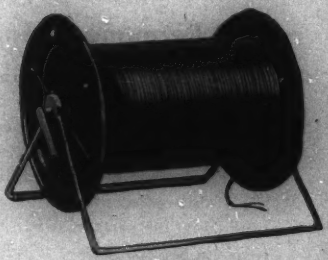

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The Cover: The first of four 30,400-kw waterwheel generators will soon be installed at the Rio Negro dam and power house in Uruguay. Construction on this 3,850-foot dam was begun in 1937 by a European contractor; the work is now being continued under the supervision of a United States company.

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G. Ross Henninger
Editor (on leave)

Floyd A. Lewis
Acting Editor

F. A. Norris
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A NEW RESOURCE HAS BEEN DEVELOPED

THE WEALTH of America has been wrought from her natural resources of fertile lands, wide forests and rich mineral deposits by the brains and muscles of her people.

But another resource is now available. A new source of wealth and well-being has been developing gradually and almost unnoticed which is tremendously important today and of still greater importance for tomorrow.

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ELECTRICAL ENGINEERING

VOLUME 63, NUMBER 2 FEBRUARY 1944

Electrification for Latin America

CHARLES A. HOWARD

ALTHOUGH the continent of South America is exceptionally well endowed by nature with valuable mineral resources, its deposits of coal that are of commercial value are extremely limited. Most of the deposits which exist are insufficient in quantity, poor in quality, or badly located with reference to consuming centers. The need for importing large quantities of fuel is a heavy burden on the economies and finances of most South American countries.

Wartime restrictions on ocean shipping and the resulting shortage of imported fuel have caused many of the South American republics to take stock of their own resources of hydroelectric power and of the possibilities for future development.

Essential substance of an article which appeared in a recent issue of *Foreign Commerce Weekly*.

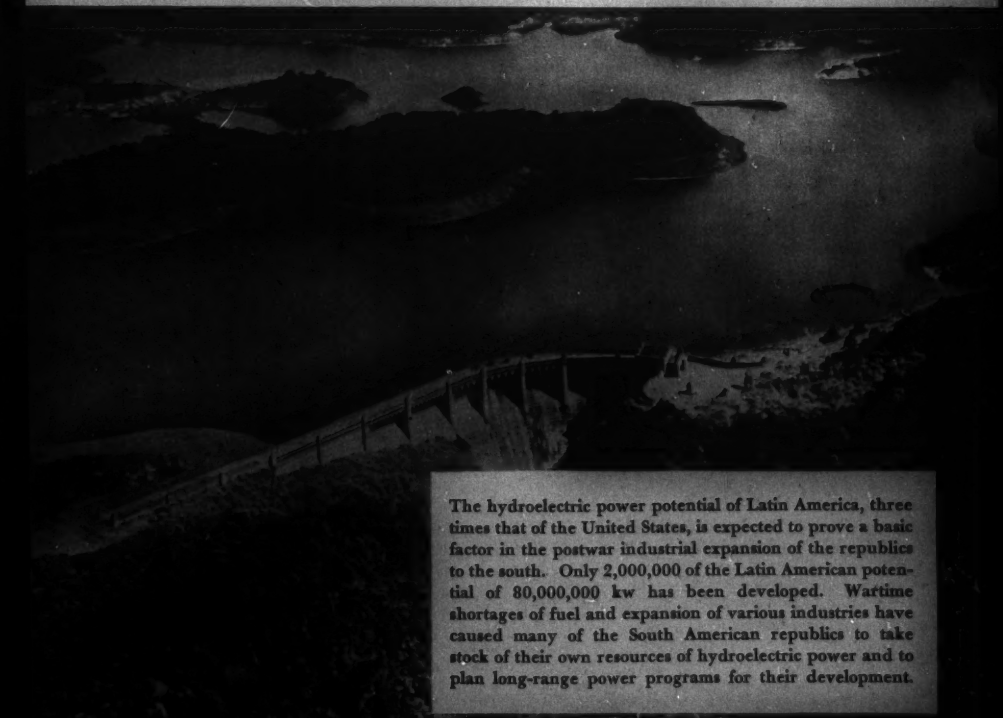
Charles A. Howard is director of the Inter-American Development Commission.

LONG-RANGE PLANNING

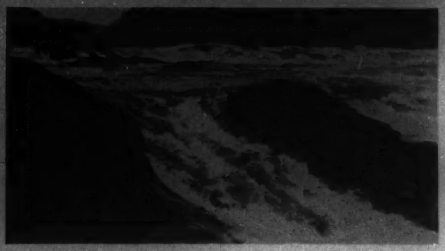
Development of potential power resources in Latin America is retarded now by the difficulty of importing equipment from the United States and Europe. Only power projects most essential to production of strategic materials and civilian needs get priority on equipment. Nevertheless, wartime shortages of fuel and expansion of various industries have stimulated interest in long-range power programs.

Many of these republics have large unexploited sources

Rio das Pedras Dam in the State of São Paulo, Brazil, as seen from downstream



The hydroelectric power potential of Latin America, three times that of the United States, is expected to prove a basic factor in the postwar industrial expansion of the republics to the south. Only 2,000,000 of the Latin American potential of 80,000,000 kw has been developed. Wartime shortages of fuel and expansion of various industries have caused many of the South American republics to take stock of their own resources of hydroelectric power and to plan long-range power programs for their development.



Rapids in River Petrohue, southern Chile. This river drains Lake Todos los Santos; in less than 15 miles it drops 500 feet. This will be the site of the Ralun hydroelectric plant to develop 50,000 kw

of electric power—especially Brazil and the mountain republics along the Andes. Chile, which is 2,600 miles long, seldom more than 100 miles wide, and has mountains exceeding 20,000 feet in height, is an outstanding example of the Andean republics.

In Central America there are sites for possible hydroelectric installations, as, for example, the Lempa River in El Salvador. But since the power needs of most of these republics are relatively small at the present time, and the initial cost of hydroelectric plants and transmission lines is relatively high, the utilization of this potential power probably will await the fuller industrialization of these republics.

Mexico has many power sites, but most of them are remote from centers of population, and Mexico, blessed with an abundance of oil for fuel, has not been under the same pressure to develop its power as have some other republics. Mexico's National Electrical Commission has a large hydroelectric project now under construction at Ixtapantongo in the municipality of Valle de Bravo, about 100 miles west of Mexico City. The first of three 38,000-horsepower generators is now about to be installed.

Both Chile and Uruguay have nationalized the future production of electric power within their borders and have programs for the complete electrification of their public services, industries, and railroads. Although Uruguay is not a mountain republic, its electrification program is one of the most advanced in South America because of long efforts to be free from the necessity of importing coal and oil for fuel.

URUGUAY

Uruguay is fortunate in having a large water-power site located right in the middle of the Republic and only 150 miles from the city of Montevideo. Work on this 3,850-foot dam on the Rio Negro to impound the largest artificial lake in South America was begun in 1937. But since, on account of the war, the original European contractor could not finish the work, which included the installation of four generating units to develop a total of 121,600 kw, the job was turned over to a United States organization.

A 30,400-kw water-wheel generator (to be supplied by a United States company) soon will be installed at the Rio Negro dam, and a transmission line to the city of Montevideo will be erected, to relieve that city of some of its dependence on imported fuels.

The total cost of the Rio Negro project, including four generators, the dam, and transmission lines, is reported to be approximately $35,000,000.

This Rio Negro dam, which will impound a lake 87 miles in length and 18 miles in maximum width, is intended as an all-purpose project. It will not only supply electric power but also provide for flood control, irrigation for farm lands, and navigation to deliver farm products to the market and manufactured products to the rural areas. Few projects offer all four of these facilities.

Several other water-power and irrigation projects are included in the long-range plans of Uruguay. These are as follows:

A dam on the Quequay River just north of the city of Paysandu, to develop 8,000 kw.

A dam on the Arroyo Cunapiru in the north of the Republic to develop 10,000 kw and to serve the cities of Rivera and Tacuarembo.

A dam on the Cabollati River in the eastern region to develop 11,000 kw and to serve Maldonado, Treinta y Tres, and other communities.

Although the average rainfall of Uruguay is 50 inches a year, rainfall fluctuates between 25 and 72 inches, and there are frequent and sometimes serious periods of drought when it may not rain for months at a time. Uruguay at present is recovering from one of its worst droughts in 40 years.

CHILE

Chile's principal centers of potential hydroelectric energy, as cited in the plans of the Chilean Development Corporation, are located in the Aconcagua region to the north of Santiago, in the Rancagua region along the Rapel River just south of the capital, and in the Osorno region which includes the chain of lakes in the South.

Although the rivers of Chile are not large, they plunge down from great heights to the sea and offer sites for high-head installations. Some of the lakes are well located for power development. In some of the southern provinces the rainfall exceeds 100 inches per year. The lakes, waterfalls, and rapids of southern Chile provide many power locations for chemical plants, smelters, and other large users of cheap power. Sites for hydroelectric plants have been surveyed at Tocopilla, Copiapo, La Serena, Coquimbo, Sauzal, Ovalle, Lontue, Maule, Laja, Pilmaiquen, and El Volcan.

The Anconcagua system will be used chiefly in the production of Portland cement. This plant, together with other power stations, also will contribute to the electrification of the railroads and provide power for new industries.

At the present accelerated rate of consumption, it is estimated that the industries of Chile will consume 600,000 tons of cement per year by 1945, or nearly double the production of 1939. Chilean interests have purchased two unused cement plants in the United States which are to be dismantled for shipment and set up in the vicinity of Coquimbo, Chile.

Guillermo More, chief of the department of energy and combustibles of the Development Corporation of Chile, describes the work in the four zones of activity of his department as follows:

"*In the southern zone* in the vicinity of the estuary of Reloncavi and Puerto Monti, surveys have been made for the 'Ralun' generating plant which will use the waters of Lake Todos los Santos and will produce 50,000 kw initial power and at least 126,000 in full development. Todos los Santos is one of a chain of beautiful lakes. It is 22 miles long, 500 feet above sea level, and only 15 miles from the

coast. The nearby and smaller Lake Chapo can produce 39,000 kw at a proposed site known as 'Canutillar.'

"*In the zone of Valdivia-Corral* the 'Manio' plant on the San Pedro River can produce 50,000 kw with a possible ultimate production of 125,000 kw. A 36-mile transmission line will bring the power to Valdivia, and 20 miles more will bring it to Corral.

"*In the zone of Talcahuano-Concepción-Penco* the 'Abanico' plant on the River Laja is now under construction with an immediate potential of 40,000 kw and a final capacity of 100,000. A 100-mile transmission line connects with the city of Concepción. The extraordinary economy achieved in the construction of the plant warrants this unusually long transmission line. This is the most economical of all the plants included in the program.

"*In the zone of San Antonio* just south of the city of Santiago, the 'Rapel' plant is to be installed on the Rapel River with an initial capacity of from 60,000 to 120,000 kw. A transmission line of 34 miles will connect it with the port of San Antonio. Work has not yet begun on this dam, but the plans are far advanced."

The Development Corporation of Chile has agreed to allocate the sum of 900,000,000 pesos for the construction of this hydroelectric plant on the Rapel River. This, it is said, will be the largest installation of its type in South America. A part of the power will be used to electrify the State railways.

The copper plant, with a capacity of 30,000 tons of finished copper a year, which Chile recently purchased from the United States, will produce copper wire for this national electrification program.

BOLIVIA

Bolivia, as one of the mountain republics, has large reserves of hydroelectric power. Plants developing some 30,000 kw are functioning at present and supplying light to cities and power to the mines. But this is only a fraction of the total possibilities in this field. Some authorities estimate that up to 4,000,000 kw could be developed in this republic on the eastern slope of the Andes if the power could be used.

Lake Titicaca, it is believed, can be made to produce 700,000 kw, which is more than is now produced by Boulder Dam. However, there is no market for this amount of power in Bolivia at the present time.

A recent decree authorizes the municipalities of Bolivia to organize mixed co-operative societies, with contributions from the State and the municipalities and from the subscribers themselves, for the exploitation of electric services. These societies are exempt from the payment of national, departmental, and municipal taxes on imports of machines and materials. The conditions for enjoying these benefits are that the societies be formed as limited liability companies of co-operative type, and that the dividends or interest on the shares be limited to 19 per cent per year on the actual paid-up capital. The State will contribute to the foundation of the municipal electric co-operative societies' resources which represent at least 50 per cent of the municipal contribution, for which purpose there will be included the necessary apportionments in the national budget of the industry services of the Ministry of Economy.

COLOMBIA

Colombia now has a total of 346 electric plants, of which six belong to the National Government or to the departments and 199 to the municipalities, and 141 are privately owned. Together they produced 293,782,492 kilowatt-hours in 1942, at a charge of 10,817,192 Colombian pesos to consumers. The consumption of electric power in Colombia more than tripled between 1933 and 1942.

Colombia is now considering the construction of a plant in the vicinity of the city of Manizales in the Department of Caldas to serve the industries of this region, the cost to be in the neighborhood of 2,000,000 Colombian pesos.

A 12,000-kw hydroelectric plant is planned for the Paez River between Paicol and Carnicerias, Department of Huila, and another plant is planned for Florencia in the Caqueta district at a cost of 70,000 pesos. Other activities include the completion of the hydroelectric plant at Trumesque, Department of Boyaca, and the beginning of work on a station at Titiribi, Department of Antioquia.

The Empresas Unidas de Energia Electrica of Bogota are constructing a dam at Soacha, 15 miles southwest of Bogota. This dam, which is 28 meters high and 560 meters long, with a capacity of 4,000,000 cubic meters will make it possible to increase the output of this company by 60,000 kw.

A capacity of approximately 161,000 kw of electricity is produced in Colombia. Of this total, about 114,000 kw are available to 2,000,000 inhabitants of cities and only 47,000 kw to inhabitants of rural areas.

A recent Colombian law, known as the Economic Plan, authorizes the issue of 50,000,000 pesos in internal four per cent 30-year bonds, to be used, in part, for the nationalization of public-utility enterprises now privately owned.

The Lages power house looking south, São Paulo, Brasil

The services of interest and amortization are to be met by the income from the enterprises nationalized.

PERU

The Government of Peru, with the aid of an export-import bank loan, is building a big hydroelectric development at Canon del Pato on the Santa River which flows into the Pacific just north of Chimbote Bay. Work on this project was initiated a year ago by Barton Jones, an electrical engineer who was previously associated with the Tennessee Valley Authority.

The project includes the installation of five generators of 25,000 kw each, and the first two units are expected to cost approximately $4,000,000. These units are scheduled to be completed by the end of 1945. Total power potential of the Santa River is estimated to exceed 500,000 kw.

Recent discoveries of magnesium and the known coal deposits serve to high-light the variety of the minerals in this region.

To augment the electric-power supply of the city of Lima, a new dam is being built a few miles east of the city. This will increase the power-generating capacity to 91,000 kw.

The Peruvian Government has approved the construction of 11 small hydroelectric plants, but work is retarded by lack of equipment. At the end of 1942 Peru had an estimated electric-power capacity of 225,000 kw, compared with 212,000 at the close of 1940. Production of electric power in Peru has increased 37 per cent since 1939, in consequence of the growing industries.

BRAZIL

Brazil has plans to harness the great São Francisco River with a series of dams and to exploit the agricultural mineral resources—iron, gold, mica, bauxite, quartz, diamonds, and copper—of this 260,000-square-mile valley.

The São Francisco River is 1,800 miles long, and most of it is navigable through the stretches between the falls and rapids indicated below as power sites. Just below the city of Itaparica and 140 miles from the mouth of this river, the great Paulo Affonso Cataracts have a fall of 265 feet. Here a hydroelectric station is projected to develop 600,000 horsepower. Another falls just above Itaparica is said to be capable of generating 200,000 horsepower. Higher up the river near Joazeiro is a third power site, and a fourth is much higher up near Pira pora. The American Technical Mission to Brazil has suggested a survey for the development of this river similar to the one used in developing the Tennessee Valley.

Brazil also plans to electrify more of its railroad mileage, and work has actually begun on that 90-mile section of the Sorocabana Railroad which connects São Paulo, the industrial metropolis of Brazil, with the important city of São Antonio. This railroad, which is double-tracked through its entire length, is owned by the State of São Paulo. This electrification project will cost over $10,000,000 and is expected to take about three years to finish.

The line is meter-gauge—that is, the rails are 39 inches apart as compared to 56½ inches on the United States railroads. The present rails are being replaced by heavier ones, and the 80-ton locomotives now in use are to be replaced by 180-ton electric locomotives, said to be the heaviest electric locomotives ever built for meter-gauge tracks. Ten of these locomotives have been ordered from the United States. For suburban service, trains of three coaches each will be used, orders for which have also been placed in the United States.

Brazil has abundant water power accessible to this line, which in the past has used imported coal and firewood. All available wood has been cut within several miles on either side of the line, and wood must now be hauled for considerable distances. The Sorocabana Railroad has a total length of 1,316 miles and serves the Pocos de Caldas region of southern Brazil which is an important center for bauxite and other minerals. One branch of the line connects with the port of Santos.

Brazil now has a total of 1,343 electric-power installations of various types supplying light and power to 2,179 communities. In 1940 Brazil had an installed capacity of 993,742 kw, of which 732,000 kw represented hydroelectric plants and 193,742 steam plants. Nearly all the hydroelectric power at present produced in Brazil is concentrated in the industrial State of São Paulo and in Rio de Janeiro.

ARGENTINA

The Argentine Republic finds itself in a relatively disadvantageous position so far as the development of hydroelectric power is concerned, because both the population and the industry of this Republic are concentrated in the Atlantic seaboard area, in and around the Province of Buenos Aires, while the water-power sites are several hundred miles away in the foothills of the Andes.

Argentina at present has 700,000 kw of installed electric power, of which 542,000 kw are in the Province of Buenos Aires. The Republic has only 31,000 kw of hydroelectric power, nearly all of which is in the Provinces of Mendoza, Cordoba, and Tucuman.

As part of the national public-works program, Argentina plans to build a number of irrigation projects impounding large lakes in the northern and western region. Wherever possible this water also will be used to produce electric power, though power is secondary to irrigation.

CONTROL BY OWN NATIONALS

A number of the South American countries have indicated their desire to have their electric-power facilities controlled by their own nationals. They desire foreign equipment and foreign technical assistance more than foreign capital in developing their water-power resources.

If they develop their water power with their own capital and distribute the power to their principal consumption centers at a reasonable cost per kilowatt, their economic positions will be materially strengthened by the extent to which their foreign-exchange requirements for the purchase of imported fuel will be reduced, as well as by the advantages which will accrue from the use of the power itself.

There should be an opportunity for engineers and manufacturers in the United States to participate on a mutually advantageous basis, in these large programs of the South American republics for water-power developments.

The hydroelectric power potential of Latin America, three times that of the United States, is expected to prove a basic factor in the postwar industrial expansion of the republics to the south. Only 2,000,000 of the Latin American potential of 80,000,000 kw has been developed. Brazil—which ranks fourth to the Soviet Union, the United States, and Canada in potential hydroelectric power—has a potential of 19,000,000 kw, which, if realized in industrial energy, would go far toward providing the power needed for industrializing that nation.

Are All the Basic Problems Solved in Electric Machinery?

M. M. LIWSCHITZ
MEMBER AIEE

THE OPINION prevails, not only among students and younger engineers but also among older engineers who are not familiar with the field of electric machinery, that the electric machine reached the peak of its development years ago and that no further progress is possible in this field. It will be shown in the following article that this opinion is wrong, that the improvement of the electric machine is steadily progressing, and that the development of the electric machine is far from its peak.

Development in engineering means better and better utilization of the active material; in the electric machine it means better utilization of the core iron and the copper. The higher the output per unit volume, the more the active material is utilized. Parallel with the reduction of the active material must go the reduction of the inactive material, that is, the material in the frame, the spider, the bearings, and so forth.

Development of electric machinery is far from static and will keep step with progress in other technical fields in the postwar period, says this author. He discusses the specific and the common problems of each type of rotating electric machine, including the method of teaching their operation, and outlines the probable direction theoretical and engineering research will take toward their solution.

Figure 1 shows the reduction of the active weight of a 1,000-hp induction motor with 1,200 rpm for the period between 1910 and 1935. The reduction of the weight of the inactive material in this instance is about the same. Since 1935, further progress has been made. The question is: "Can the extent of the progress made between 1910 and 1935 be repeated in the future?"

The answer is: "Yes!" It will be achieved step by step by solving the problems which handicap the further utilization of the materials, and, also, by introducing new developments. These possible new developments will be discussed later on. First, some old as well as new problems will be outlined, the solution of which will open the way for further development of the electric machine.

Electric machines can be divided in two main groups. The first group includes the induction motors and the synchronous machines; the second group includes the d-c machines and the a-c single-phase series motor, that is, the transportation motor. Between these two groups lie, as connecting members, the rotary converters and the three-phase a-c commutator machines.

The main feature of the first group is that its armature field is uniquely determined by the load. For any given load there is a fixed magnitude of the armature field and a fixed position of this field relative to the primary field. In these machines it is not possible to cancel the effect of the armature field by a compensating winding. A common characteristic of machines in this group is operation on the transformer principle.

The main feature of the second group is that the position of the armature field is independent of the load; it is determined solely by the position of the brushes on the commutator. Here, the effect of the armature field can be cancelled out by a compensating winding. In the a-c transportation motor, moreover, this cancellation is unavoidable.

We shall consider some of the actual problems of the first group; then, some of the actual problems of the second group; and, finally, some of the problems common to all electric machines.

INDUCTION MOTORS

Starting with the induction motor, one has to consider, at first, the harmonics produced by the windings in the air gap of the machine. These harmonics give rise to the following troubles: asynchronous torques, synchronous torques, and mechanical vibrations which produce noise. The asynchronous torques cause dips in the torque-speed curve of the machine which may prevent the motor from attaining normal speed. The synchronous torques cause cusps in the torque-speed curve; a large synchronous cusp at standstill may prevent the motor from starting, and a large synchronous cusp during running may prevent the motor from reaching its normal speed.

Table I shows the harmonics produced by the stator, as well as by the rotor, of a four-pole squirrel-cage induction motor with 72 slots in the stator and 58 slots in the rotor. The first column represents the harmonics produced by the stator winding; the harmonics contained within the square are the dangerous slot harmonics. Each stator harmonic produces rotor harmonics of the order shown in the horizontal rows of the table. The determination of the order of these harmonics is given in the accompanying formula, where Q_2 is the number of rotor slots and K_2 is any positive or negative integer including zero.

In the first column of the rotor harmonics, that is, in the column that corresponds to $K_2=0$, the order of the rotor harmonics is the same as that of the stator har-

M. M. Liwschitz is with the Polytechnic Institute of Brooklyn, Brooklyn, N. Y., and is also consulting engineer for Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

monics. Each of these rotor harmonics produces with the corresponding stator harmonic an asynchronous torque. All other rotor harmonics produce synchronous torques.

By using a proper slot combination, that is, a proper ratio between the number of stator and rotor slots, one is able to avoid entirely the synchronous cusps and thus insure the starting of the motor. One cannot avoid the asynchronous torques, but they can be reduced to a permissible amount by using a proper slot combination and a proper coil pitch.

The choice of a proper slot combination also introduces the problem of stray load losses; that is, of additional losses in the iron and in the copper due to the harmonics. Only a few years ago one could find on the market induction motors with stray load losses that were relatively high and that necessarily caused an appreciable reduction of the efficiency. We have learned how to reduce this extra loss to a small amount even in small machines, thereby increasing the efficiency of the induction motor considerably.

The third trouble produced by the harmonics, that is, the mechanical vibrations connected with noise, hinders perfection in the induction motor, especially in machines with fabricated frames.

In the electric machine, the lines of the magnetic induction pass radially through the gap. Therefore, at any point in the gap, there will be a radial force that is proportional to the square of the induction. Since the induction, at any point, is equal to the sum of the stator harmonics and the rotor harmonics, the evaluation of this quantity shows that there are forces in the gap produced by the stator harmonics only, forces produced by the rotor harmonics only, and forces produced by the stator harmonics in co-operation with the rotor harmonics.

A simple mathematical calculation makes it possible to represent these forces as stationary forces and traveling force waves. Like the rotating field that produces the torque of the machine, the force waves travel in the gap around the stator without change in amplitude. Since there are many harmonics produced by the stator and rotor, there will be in every machine many traveling force waves with different numbers of poles.

The kind of distortion of the stator core caused by a stationary force is shown in Figure 2. This force has no poles; it is constant around the stator at any instant,

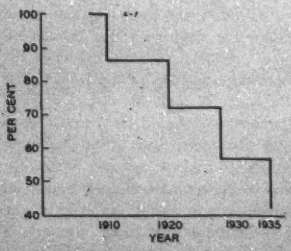


Figure 1. Reduction in weight of the active materials in a 1,000-horsepower six-pole 1,200-rpm induction motor

Table I. Slot Harmonics in a Four-Pole Squirrel-Cage Induction Motor With 72 Slots in the Stator and 58 Slots in the Rotor

Stator	Rotor				
	$m=K_1\frac{Q_2}{p}+n$			$Q_2=58$	
n	$K_1=0$	$K_1=+1$	$K_1=-1$	$K_1=+2$	$K_1=-2$
+1	+1	+30	−28	+59	−57
−5	−5	+24	−34	+53	−63
+7	+7	+36	−22	+65	−51
−11	−11	+18	−40	+47	−69
+13	+13	+42	−16	+71	−45
−17	−17	+12	−46	+41	−75
+19	+19	+48	−10	+77	−39
−23	−23	+ 6	−52	+35	−81
+25	+25	+54	− 4	+83	−33
−29	−29	0	−58	+29	−87
+31	+31	+60	+ 2	+89	−27
−35	−35	− 6	−64	+23	−93
+37	+37	+66	+ 8	+95	−21

□ Slot harmonics.

but it changes its value with a certain frequency from a positive maximum to a negative maximum. The result is a periodical increase and decrease of the core diameter. The kind of distortion caused by force waves with two poles, four poles, and six poles is shown in Figure 3. Whereas the two-pole force wave flattens the stator core, the four-pole force wave makes it oval. The six-pole force wave, as well as the force waves with a greater number of poles, makes the stator core polygonal. The oval or the polygon is not at standstill, of course; it travels around the machine together with the force wave that produces it.

Whereas the stationary forces produce radial vibrations of the core, the traveling force waves produce flexural vibrations. The consequence of the mechanical vibrations is noise.

The stator is, in general, stiffer with respect to short-wave distortion than to long-wave distortion. This means that the force waves with a small number of poles have to be avoided; especially dangerous is the two-pole force wave.

The frequency of the noise produced by the harmonics is of great importance. As mentioned before, there exist in the gap force waves produced by the stator harmonics only, force waves produced by the rotor harmonics only, and force waves produced by the stator and rotor harmonics together. It can be shown easily that the frequency of the noise produced by the stator harmonics only is equal to twice the line frequency. This noise usually is not disturbing. The noise produced by the rotor harmonics only has double line frequency or a relatively high frequency and, also, usually is not disturbing. However, the noise produced by the stator harmonics in co-operation with the rotor harmonics may be very disturbing, as the frequency is approximately the slot frequency, that is, between 800 and 2,000 cycles.

The noise may become intolerable when the natural frequency of the core, or of any other mechanical part which is connected with the core, is the same as the frequency of the vibrations produced by the harmonics (resonance). Machines with fabricated frames are especially sensitive to the forced vibrations produced by

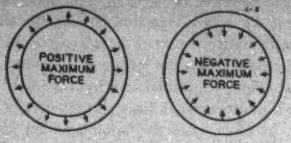


Figure 2. Distortion of the stator core caused by a stationary force

the harmonics. The cover of such machines is usually a relatively thin plate that behaves, with respect to vibration, as a membrane having many natural frequencies. Since there are many force waves with different frequencies, the possibility exists that one or more forced frequencies will coincide with the natural frequencies of the membrane. One cannot avoid the harmonics and the force waves produced by them. By proper chording of the stator winding one can reduce the harmonics of lower order, and by proper skewing the influence of the dangerous slot harmonics can be reduced, but in the case of resonance, even a very weak harmonic may produce a heavy noise. The noise problem could be brought nearer to its solution if one were able to determine the natural frequencies of the stator. The stator is a complicated structure consisting of the core laminations and bolts or bars which bind the laminations together, of the frame, cover, shields, and so forth. Here is a difficult problem that has to be solved yet, especially with respect to flexural vibrations.

The natural frequency of the stator is independent of the speed of the motor, but the forced frequencies produced by the harmonics depend on the speed. Therefore, it is more difficult to avoid resonant points in a machine with variable speed than in a machine with constant speed. In Figure 4, the axis of abscissas represents the number of force poles (or nodes), and the axis of ordinates, the natural frequencies. The curve represents the natural frequencies of the stator. The vertical lines represent the frequencies for different force waves having 6, 12, 16, 24, and 32 force poles. The upper point of each vertical line corresponds to the normal speed of the motor; the point at the bottom of each vertical line corresponds to the lowest speed of the motor. If the machine ran at its normal speed only, resonance between the forced and natural vibrations would not occur. Since the rotor speed is variable, the forced frequency of each force wave goes through a wide range and the intersection points will give resonance.

Figure 4 refers to an induction motor with speed variation over a wide range. The a-c variable-speed drive for smaller output is accomplished by a-c commutator motors and will be discussed later. The a-c variable-speed drive for large output uses the induction motor as a primary machine, and the methods which are used are neither simple nor inexpensive.

There are 4 different methods to vary the speed of an induction motor having fixed stator frequency:

1. By using a rotary converter which is connected to the slip rings of the rotor of the induction motor.

2. By using an a-c commutator machine which is connected to the slip rings of the induction motor.

3. Through doubly feeding, that is, stator and rotor of the induction motor are connected to two sources of different frequencies.

4. By a rheostat in the rotor circuit.

The first and second methods are based upon the fact that a voltage which is in phase with the line voltage, or opposite to it, will change the speed of the induction motor when impressed on its rotor. When it is desirable that the induction motor does not lose its character as an induction motor, that is, its ability to change speed with the torque, the secondary machine must be able to adjust its frequency automatically to the slip frequency of the induction motor. The rotary converter and the three-phase commutator machine are able to effect this adjustment. This is one of the reasons why the rotary converter and a-c commutator machines have been used relatively often for speed control of the induction motor.

The scheme of connection between induction motor and rotary converter is shown in Figure 5. When the torque on the shaft of the induction motor must increase with decreasing speed, a d-c machine is necessary on its shaft. When the torque must decrease with decreasing speed, two d-c machines and a synchronous machine or induction motor are necessary. Both arrangements are known under the name of Kramer–Cascade. The variation here is possible only below synchronism. The speed can be reduced 30 to 40 per cent of the normal value.

Figure 6 shows the induction motor in connection with the rotor-excited a-c commutator machine. The stator of the commutator machine has a compensating winding only. The excitation is delivered from the line to the rotor winding through slip rings. The compensating winding in series with the commutator is connected to the slip rings of the induction motor. Speed variation is possible above, as well as below, synchronism. The machine has no interpoles. The commutation therefore, is sensitive, and limits the input of this machine to approximately 200 kva.

Figure 7 shows the scheme of the Scherbius machine. In this machine, the three-phase system is resolved into three single-phase systems. The purpose is to make space for interpoles. The compensating winding is located in the poles. The windings of this machine are not simple. Each pole has three compensating windings, one for each phase. The interpole has three windings, two for the elimination of the electromotive force of self-inductance, and the third to reduce the transformer electromotive force.

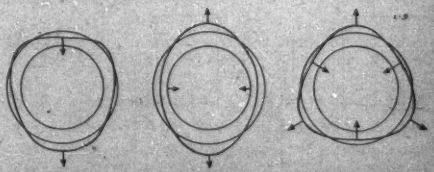


Figure 3. Distortion of the stator core caused by (left to right) two-pole, four-pole, and six-pole traveling force waves

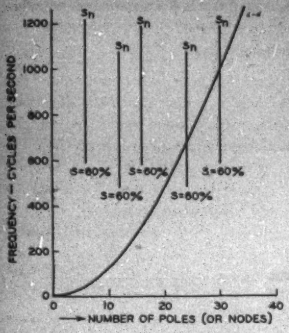


Figure 4. Forced frequencies in induction motors having wide speed variations. Intersections with the stator natural-frequency curve indicate points of resonance

Whereas the rotor-excited a-c commutator machine must be mechanically coupled with the induction motor, this is not required for the Scherbius machine. Figure 8 shows the Scherbius machine driven by an induction motor, but it can also be driven by a separate synchronous machine. The field winding is connected to the slip rings of the induction motor. The scheme, as shown in Figure 8, is applicable when speed variation below synchronism only is required. For speed variation above synchronism, a small frequency changer coupled with the induction motor is necessary, as shown in Figure 9. Since the Scherbius machine has interpoles, it can be built for a much larger input than the rotor-excited a-c commutator machine. Considering commutation, the Scherbius machine can be used for a speed variation of plus or minus 30 per cent of the normal speed.

When a speed variation over a wide range for a large induction motor is required, neither the Kramer–Cascade nor the Scherbius machine can be used. In this case the arrangement shown in Figure 10 has been applied. The rotor of the induction motor is connected to a synchronous machine which is driven by a d-c machine. Thus, the induction motor is doubly fed. It has the character of a synchronous machine since its speed is uniquely determined by the frequency of the line and the frequency of the synchronous machine. Besides the synchronous machine and the d-c machine, a second d-c machine and a second a-c machine (a synchronous machine or induction motor) are necessary. Speed variation is possible below synchronism only.

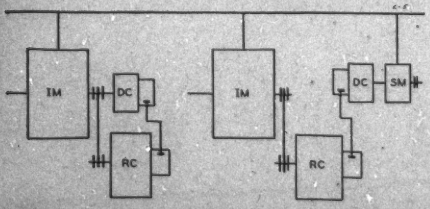


Figure 5. Schematic diagram showing the use of a rotary converter for varying the speed of a large induction motor

This arrangement for speed variation is economical as well as the arrangements mentioned before, since the slip energy is applied to increase the torque of the motor or is sent back to the line. Speed control by a rheostat in the rotor circuit is uneconomical, since the slip energy is lost. However, in some cases the latter method is preferred to the others for its simplicity.

It cannot be said that the solutions for speed variation of the induction motor are simple. When the solution is simple, as in the case of the rotor-excited a-c commutator machine, the commutation is sensitive and the range of speed variation is limited.

SYNCHRONOUS MACHINES

We turn, now, to the synchronous machine. The influence of the harmonics here is not so great as it is in the induction motor because of the larger air gap of the synchronous machine. Yet, in the salient-pole machine, the harmonics may produce troublesome noise. The investigation of the noise produced by the harmonics is more difficult here than in the induction motor, because here there is another source of noise, namely, the noise produced by the pole tips and the stator teeth. A study of the noise produced by the harmonics in salient-pole machines is necessary.

An important problem for the synchronous generator with salient poles is the telephone-interference factor. This factor depends on the shape of the pole head, on the saturation, on the stator slots, and on the damper winding. The existence of a damper winding is usually connected with an increase of the telephone-interference factor. Sometimes a little change in the distribution of the damper bars reduces the telephone-interference factor to one half or even a third of its value. An investigation of the influence of the different quantities on the telephone-interference factor is important for the medium-size salient-pole machines. The usual means used to reduce the telephone-interference factor, such as the increased gap, the sinusoidal gap, or reduction of the saturation, handicaps the development of the synchronous machine.

The damper winding of a salient-pole machine is an asymmetrical winding. The damper bars are arranged in the pole head only. There are no bars in the interpolar space. This makes any calculation in which the damper winding plays a part very difficult.

Investigation of the salient-pole machine is possible only on the basis of the two-reaction theory. This theory considers separately the direct axis and the

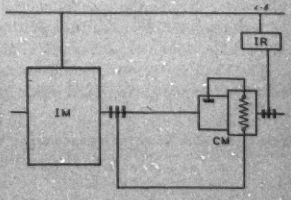


Figure 6. Schematic diagram showing the use of a rotor-excited a-c commutator machine for varying the speed of a large induction motor

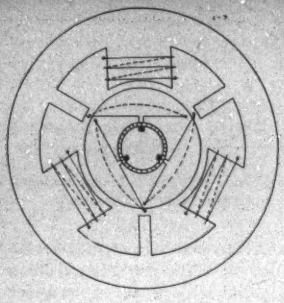


Figure 7. Schematic diagram of the Scherbius machine

quadrature axis. Calculations on the synchronous machine are based on the constants of its windings in both of these axes. There still exists no method for determining the constants of the damper winding with sufficient accuracy.

This hampers the accurate determination of the starting performance of the synchronous motor, of the subtransient reactances in both axes, of the damping torque, and of the synchronizing torque.

The starting torque, the starting current, and the pull-in torque, depend primarily on the constants of the damper winding. The accuracy of the calculation of these quantities on the basis of our present knowledge is plus or minus 15 per cent. When guarantees have to be met, the designer calculates with a certain margin, and margin usually means an increase of the material in the machine. Thus, much more work has to be done on the solution of the starting problem of the synchronous motor.

In order to reduce the manufacturing costs, the connection of the damper rings between the single poles often is omitted. The current distribution in the damper bars of each pole, in this case, is independent of that of the neighbor poles, and, as a result, circulating currents flow between the end bars, through the end laminations of the poles, and through the rotor core. Of course, this makes the computations connected with the damper winding much more difficult.

It has been observed that an unbalanced short circuit in the line may cause high overvoltages, and it has been found that the principal factor for determining the magnitude of these overvoltages is the ratio between the subtransient reactance in the quadrature axis and the subtransient reactance in the direct axis.

When the damper segments between the different poles are disconnected, the subtransient reactance in the quadrature axis is, of course, much larger than in the case when they are connected and, also, much larger than the subtransient reactance in the direct axis. In long machines, the circulating currents between the poles reduce the subtransient reactance in the quadrature axis, but, still the ratio is considerably larger than one. A complete solution of this problem will be possible only when more theoretical work is done on the damper winding with respect to its resistance and reactances in both axes.

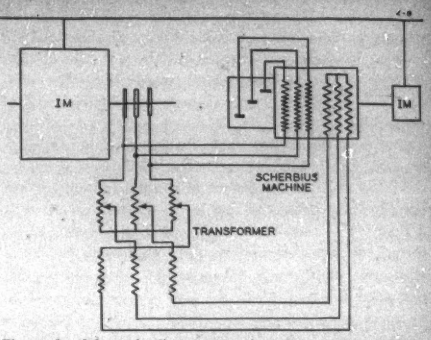


Figure 8. Schematic diagram showing the usual connection between the induction motor and the Scherbius machine

For investigation of stability problems in which the synchronous machine is involved, an exact knowledge of the damping torque and synchronizing torque produced by it is necessary. Although the two-reaction theory in its final form gives the possibility of calculating these torques, even when the primary resistance has to be taken into account, the accuracy of the calculations depends on the constants of the machines. The constants involved again are the constants of the damper winding and, in addition, the synchronous reactances of both axes. These latter depend on the saturation of the machine and on the load. There exists no exact method of calculating the synchronous reactances that takes into account the saturation with satisfactory accuracy, and further theoretical work has to be done here too.

D-C MACHINES

Proceeding to the d-c machine, we meet an old problem that is still new, namely, that of commutation. The commutation is not only an electrical problem; it is a mechanical problem and a chemical problem as well. The construction of the brush holder, the vibrationless running of the brushes and commutator, the brush pressure, and the chemical composition of the brushes are all of primary importance. However, if we limit our considerations to the electrical problem only, we must say that this problem has not been entirely solved. The gap of the interpole and the ampere turns of the interpole can be calculated to a satisfactory accuracy, but not so accurately that changes of the gap on the test floor can be avoided. On a certain percentage of d-c machines, the interpole gap has to be adjusted after the machine has been assembled, and this means a waste of time and money.

One of the difficulties lies in the determination of the electromotive force induced in the short-circuited coil through self-inductance and mutual inductance. The exact determination of the coefficient of self-inductance is not simple. Much more difficult is the determination of the coefficient of mutual inductance. But even if we

were able to calculate these coefficients with satisfactory accuracy, the solution of the problem requires that the current in the short-circuited coil be determined as a function of time. This leads to complicated differential equations that can be solved under simplifying assumptions only.

For this reason, the whole theory of commutation is simplified for practical use. The coefficient of self-inductance and the coefficient of mutual inductance are combined as one factor, and for the current variation as a function of time an average value is assumed. The formula for the electromotive force induced in the short-circuited coil through self-inductance and mutual inductance is

$$e = 0.507 l_i N_c V_a A \xi 10^{-8} \text{ volts}$$

where l_i is the length of the interpole, N_c is the number of conductors per commutator bar, A is the number of ampere conductors per unit circumference of the armature, V_a is the velocity of the armature and ξ is a factor which takes into account the coefficient of self- and mutual inductance. A is calculated by using the load current of the armature.

Although the formula is simple, it includes all of the principle factors which influence the commutation. We see from this formula that if it were possible to reduce the factor ξ, the magnitude of A could be increased. The output of the machine is directly proportional to A and, thus, the output could be increased. Or, instead of increasing the magnitude of A, the armature velocity V_a could be increased with a decrease in ξ. This, again, means an increase in the output of the machine.

A decrease of the factor ξ can be achieved through reduction of the slot leakage. An arrangement to achieve this is shown in Figure 11. A solid copper bar of L shape is put into the slot. The reduction of the slot

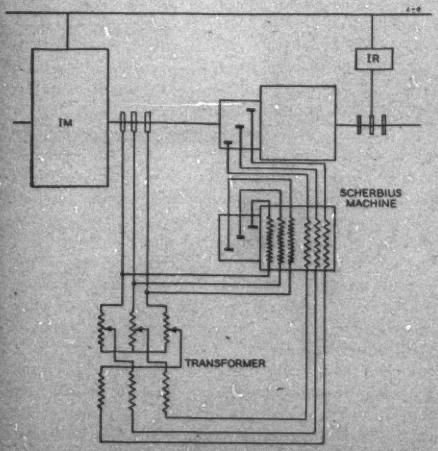


Figure 9. Schematic diagram showing the use of the Scherbius machine for speeds above synchronism

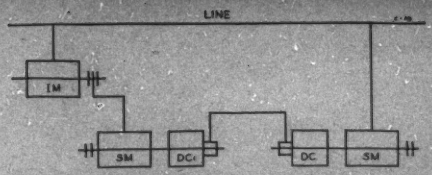


Figure 10. Schematic diagram of doubly fed induction motor for wide speed variations below synchronism

leakage is considerable but, unfortunately, losses arise in the L bar that reduce the efficiency. The conditions are similar to those which exist in the squirrel-cage rotor with deep bar. Some large European d-c machines have been provided with the L bar.

Figure 12 shows another arrangement to reduce the slot leakage. This arrangement is not so effective as the L bar with respect to the reduction of the slot leakage, but the losses are smaller. Two short-circuited coils are put into the slot so that the lower conductor of each coil is at the bottom of the slot, whereas the upper conductor lies at the top of the slot directly under the edge. In order to reduce the losses, the conductor consists of some copper wires of small diameter or of copper sheets. Thus, the conductors are flexible and facilitate the assembling of the winding. This method of reduction of the slot leakage also has been used in Europe. As we see, improvements in the commutation of the d-c machine are possible, and undoubtedly will be made. A further study of the commutation problem is necesary.

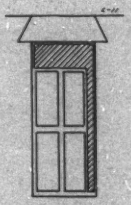


Figure 11. Use of an L-shaped copper bar to reduce slot leakage

A-C COMMUTATOR MOTORS

In a-c commutator motors the commutation plays a much greater part than in the d-c machines, because of the fact that in the short-circuited coil an additional electromotive force is induced, namely, the transformer electromotive force. While the electromotive force of self-inductance is proportional to the current and to the speed of the machine, the transformer electromotive force is proportional to the flux and to the line frequency. A simple interpole winding is not able to correct for these two electromotive forces, because they are produced by different physical quantities. Special arrangements are necessary to meet both troublesome electromotive forces.

The transformer electromotive force cannot be cancelled through transformation by an auxiliary flux. Like the electromotive force of self-inductance, the transformer electromotive force must be cancelled by an electromotive force that is induced in the short-circuited coil through rotation in an auxiliary field. This is possible at a single speed only. At all other speeds a residual electromotive force will exist in the short-circuited coil.

The conditions are especially bad at standstill. There is no reduction at all of the transformer electromotive force at standstill. This situation leads to a reduction of the flux and, where possible, also to a reduction of the line frequency, as in the transportation motor. Thus, due to the transformer electromotive force, the a-c

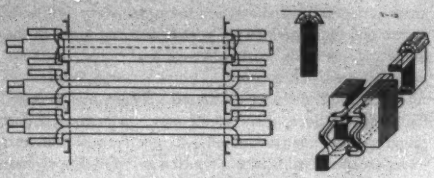


Figure 12. Method of reducing slot leakage by use of short-circuited coils

commutator motors are oversized in comparison with the induction motor or synchronous motor of the same output.

The best existing a-c commutator motor, as far as the commutation is concerned, is the single-phase series motor (the transportation motor). This is so because the transportation motor has an interpole winding and a special arrangement to reduce the transformer electromotive force: a resistance parallel to the interpole winding shifts the current in it in such a manner that one component of the interpole flux takes care of the electromotive force of self-inductance while the other component takes care of the transformer electromotive force.

In three-phase commutator motors one must consider the electromotive force induced in the short-circuited coil by the rotating field instead of the transformer electromotive force.

Figure 13 shows the scheme of the three-phase series motor. A transformer is necessary between the stator and commutator. Torque and speed are changed through brush shifting.

Two kinds of the three-phase shunt motor are on the market—the stator-fed and the rotor-fed motor. Figure 14 shows the scheme of the stator-fed three-phase shunt motor. The stator has a main winding connected to the line and an auxiliary winding connected to the commutator. A small induction regulator is provided in order to change the armature voltage and speed.

The rotor-fed three-phase shunt motor is shown in Figure 15. The rotor has two windings, one connected with the slip rings, the other connected with a commutator. The slip rings are connected to the line.

The operation of this motor is the same as that of an induction motor with the primary winding in the rotor, the secondary winding in the stator, and a commutator machine that impresses a voltage on the secondary winding.

In order to change the magnitude of the impressed voltage, two sets of brushes are necessary on the commutator, shifted, with respect to each other, in the axial direction. The beginnings of the three stator phases are connected to one set, the ends to the other set. When the brushes that belong to the same phase are in the same line, that is, when they are located on the same commutator bar, the impressed voltage on the stator is zero. In this position of the brushes, the machine behaves as a normal induction motor. By moving one brush set with respect to the other, in one or the other direction, it is possible to change the magnitude and direction of the impressed voltage and, therefore, the speed also.

The two rotor windings shown in Figure 15 can be connected to a single winding.

As we see from the schemes of the three-phase motors, nothing is provided to eliminate the electromotive force of self-inductance in the short-circuited coil. An arrangement to reduce the second electromotive force of the short-circuited coil is not possible because of the fact that we are dealing with a rotating field. Hard brushes, in this case, are the single remedy against bad commutation. An improvement in the commutation can be achieved by putting resistance between the risers and the winding or special winding connected to the commutator, but this is neither simple nor economical.

Because of the lack of arrangements for improving the commutation, the three-phase a-c commutator motor is limited to a small output. For a larger output it becomes sensitive with respect to commutation.

Many thousand a-c commutator motors for smaller output have been in satisfactory operation for years. Yet the a-c variable-speed drive is still awaiting a solution.

PROBLEMS COMMON TO ALL ELECTRIC MACHINES

We proceed, now, to the problems common to all electric machines. These are the loss problem and the cooling problem.

Losses. There are four kinds of losses in the electric machine—copper, iron, windage, and friction losses. The copper-loss problem can be considered solved. We are able to build even large machines with approximately ten per cent extra loss in the copper. In small machines, the extra copper loss is small because of the small size of the conductor. In medium and larger machines, a proper stranding reduces the losses. In large machines, special means may be necessary to keep the extra loss down. These means are the group transposition, the inverted-turn transposition, the twisted-lead transposition, or, finally, the Roebel transposition, which is made up inside the slot, whereas the three other kinds of transposition are made in the end winding or in the leads.

Great improvement can be expected in the iron-loss problem through the use of cold rolled steel. Much progress has been made in transformers by this means. However, there is a factor that limits the use of this steel in electric machines. Its good properties—high magnetization and low losses when magnetized in one certain direction only—make it adaptable to the stationary field of the transformer. But, in the electric machine, with rotary magnetization, that is, magnetization in all

directions, the cold rolled steel must be equalized for all directions before it can give here the same good results as in the transformer.

Not all iron losses in the electric machine are due to the main flux. A large part is due to mechanical rotation. If we consider, for example, the no-load losses of an induction motor, approximately one third is produced by the main flux and two thirds through mechanical rotation. This ratio, one third to two thirds, depends on the slot combination chosen and is valid for a well-designed motor. At no load, a badly designed motor may have the ratio between the iron loss due to the main field and the iron loss due to the mechanical rotation, one to six, and more. In general, in the electric machine, the iron losses depend not only on the quality of the iron, but also on the design. However, in a well-designed machine, an improvement in the quality of the iron will reduce the iron loss. Progress of the same kind as in the transformer can be expected in the electric machines, also.

Not very much attention has been paid to the efficiency of the fans in electric machines except those in turbogenerators, where the friction losses play a great part. Improvements in the fans of all other machines can be made. However, much more important than the efficiency of the fan, is the air distribution produced by it. The air distribution in the machine is of primary importance for its cooling.

Heating. The heating problem is still far from its solution. The electric machine is a body composed of many parts having different heat conductivities. It is not a solid body; it is divided by air ducts into sections. The heat has to be transferred to the air in these vents, to the air at the end windings, and to the air at the cylindrical surfaces of the core iron. The heat-transfer constants at all these spots have a great influence on the cooling of the machine. Since the heat conductivities of all insulating materials used in the machine are involved, a dozen different heat conductivities, and at least four heat-transfer constants have to be taken into account for the solution of the heat problem. These four heat-transfer constants are those of the end windings, of the coils in the vents, of the iron in the vents, and of the iron in the gap of the machine. All heat-transfer constants depend mainly on the air velocity. For example, the heat-transfer constant of the end winding is equal to 0.025 watt per square inch per degree centigrade when the air velocity between the end windings is equal to 590 feet per minute, and to 0.038 watt per square inch per degree centigrade when the air velocity is equal to 1,180 feet per minute.

When the width and depth of the coil are small in comparison to the length of the conductor, the heat problem can be treated as a one-dimensional problem, that is, it can be assumed that there is no temperature change in the transverse section of the conductor, and that a temperature change exists only in the axial direction of the conductor. In large machines with deep slots, the heating problem of the winding must be treated as a two-dimensional problem.

The solution of the heating problem leads to a system of many simultaneous differential equations. Yet, the problem can be solved, and it will be solved. Competition after the war will force engineers to solve some of the problems they have postponed.

How important the solution of the heat problem is can be seen from Figure 16. This figure relates to a three-phase salient-pole synchronous machine for 1,600 kva, 6,600 volts, and 24 poles. Of the total losses in the stator, 41 per cent are iron losses, and 59 per cent are copper losses. There are two ways through which iron losses can be transferred to the air. These are the inner cylindrical surface of the stator core, and the vent and finger plates. Approximately 40 per cent of the iron losses are absorbed by the air in the gap and 60 per cent of the iron losses are absorbed by the air in the vents.

There are three ways through which copper losses can be transferred to the air. These are via the end windings, the coil portions which lie in the vents, and the coil portions which lie in the core iron. We see from Figure 16, that approximately 55 per cent of the copper losses are absorbed by the air that surrounds the end windings, approximately 12 per cent of the copper losses are absorbed by the air which goes through the vents, and the remaining 33 per cent, is transferred to the core iron. The larger the part of the copper losses that is transferred to the iron, the lower will be the temperature of the copper at the hottest spot, which is the center of the middle stack of laminations, and the lower will be the average temperature rise of the winding as determined by resistance test.

It is wrong to leave the cooling of the winding mainly to the end windings, because this leads to hot spots.

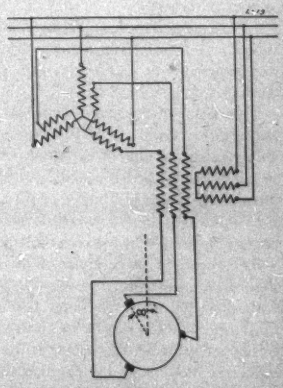


Figure 13. Schematic diagram of a three-phase series motor

It is still worse to transfer heat from the iron to the winding, thus forcing the end windings to transfer to the air the total copper losses and a part of the iron losses.

A correct distribution of the heat in the winding between the three parts that transfer this heat is of great importance for the further development of the electric

machine. But, only the solution of the heat problem will enable us to make this distribution in a desirable way.

INSULATING MATERIALS FOR HIGH TEMPERATURES

There is another prospect for further progress in electric machinery. This is the improvement of insulating materials with respect to their ability to resist higher temperatures. Tests are now in progress on materials that are able to withstand very high temperatures. Since the permissible temperature rises in electric machines are determined by the insulation materials only, a higher output for the same weight will be achieved by new materials. The higher the temperatures that can be admitted, the more one will have to know about the heat distribution and heat transfer in the machine. Study of the heating problem must go hand in hand with an increase of the temperatures.

METHOD OF TEACHING ELECTRIC MACHINERY

As we have seen, many problems in electric machinery, both old ones and new ones, are awaiting solution. We have seen further, that there are possibilities for an increase of output at the same weight, or for a decrease of weight at the same output. Both mean better utilization of the material. We can expect the postwar period to be one of progress in electric machinery, and this progress will keep step with progress in other technical fields.

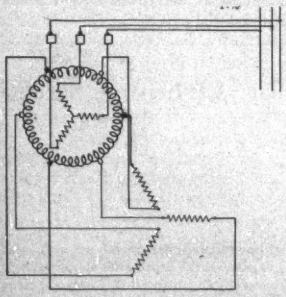


Figure 14. Schematic diagram of a stator-fed three-phase shunt motor

At this point it should be noted that not all the problems in electric machinery have been touched upon, and that there are many more problems which could be discussed. Some new types of electric machines, as, for example, the electric coupling and the Amplidyne, have not been even mentioned. There is one more problem that should be pointed out, however. This is the method of teaching electric machinery.

The progress in electric machinery, as in other fields, has been made through deeper penetration into the matter, and further progress will be made through still more thorough study of the phenomena that occur in the machine. This means that the teachers will have to enlarge their programs. A lengthening of the study time is not desirable. Still less so is an overloading of the mind of the student by more matter. Therefore, other methods of teaching will have to be found—methods based on logic, not on memory.

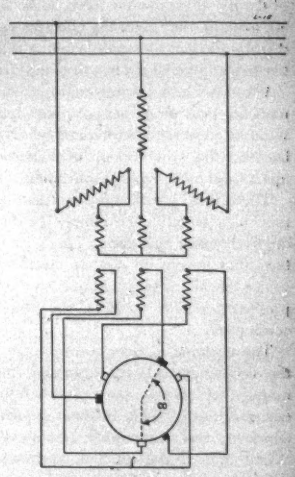


Figure 15. Schematic diagram of a rotor-fed three-phase shunt motor

When one talks to an engineer who is more or less familiar with the field of electric machines, and who mentions the different kinds of machines as, for example, the synchronous machine or the d-c machine, one gets the impression that he uses different thought processes for each kind of machine. He considers the machines as entirely different.

For the simplest example, consider the electromotive force induced in the windings of the synchronous and of the d-c machine. When the engineer who works in a-c machines is asked about the electromotive force of the a-c machine, he writes the formula:

$$E = 4.44 f N K_d K_p \Phi 10^{-8} \text{ volts}$$

But, if he were asked about the electromotive force induced in a d-c machine, he probably would try to apply an entirely different method of attack or would refer to a textbook. This would not be necessary if he

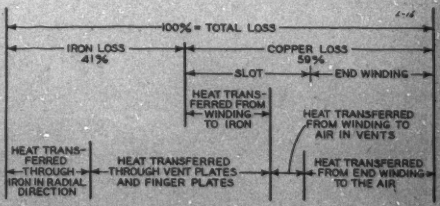

100% = TOTAL LOSS
IRON LOSS 41%
COPPER LOSS 59%
SLOT
END WINDING
HEAT TRANSFERRED FROM WINDING TO IRON
HEAT TRANSFERRED FROM WINDING TO AIR IN VENTS
HEAT TRANSFERRED THROUGH IRON IN RADIAL DIRECTION
HEAT TRANSFERRED THROUGH VENT PLATES AND FINGER PLATES
HEAT TRANSFERRED FROM END WINDING TO THE AIR

Figure 16. Heat-loss diagram for 1,600-kva synchronous generator

knew that the d-c machine is also an a-c machine, except that it has a special device, the commutator. He could then use the same formula as for the a-c machine. A correct knowledge of the function of the commutator would tell him that the brushes pick up the amplitude of the a-c electromotive force, so he would multiply the a-c formula that gives the effective value by $\sqrt{2}$. The distribution factor of a d-c winding is $2/\pi$, or the diameter divided by half the length of the circle.

When one asks a young engineer why the synchronous machine runs synchronously, one does not often get a suitable answer. The student never thinks about this, because the synchronous machine is usually treated apart from other types of machines.

There is no justification for treating the synchronous machine, the induction motor, the d-c machine, and so on, as different machines. There are three fundamental laws that govern all electric machines, and these laws suffice for the investigation of even the more complicated problems, as, for example, the skin-effect problem in conductors.

The teaching of electric machinery should start with the fundamental laws, explaining them in a general manner so that they can be applied to all kinds of electric machines. This includes information about the windings, and a complete treatment of the magnetic circuit and of the leakage reactances for all electric machines.

Teaching the operation of the electric machines should follow. The shortest way to teach the operation of the electric machines is to start with the transformer, since the transformer is the simplest a-c apparatus. The induction motor must follow, because the induction motor is a general transformer. It transforms not only the voltage, but also, the frequency. It is scarcely necessary to mention that we use, according to the AIEE standards, the equivalent circuit of the transformer in order to determine the performance of the induction motor.

After an explanation of the fundamentals of speed control of the induction motor by the use of an impressed voltage on its slip-rings, the synchronous machine appears as a special case of the induction motor, namely, the case where the impressed voltage is a d-c voltage. The use of the transformer diagram for the synchronous machine is then justified. The two-reaction theory that is used in synchronous machines is not a new principle that changes the character of the synchronous machine as a transformer. It is only a refinement necessary for the salient-pole machine.

The d-c machine should follow the synchronous machine. Yet, the d-c machine can be treated before, or parallel with, the synchronous machine when it is emphasized that the d-c machine is actually an a-c machine. The commutation problem is an a-c and not a d-c problem. The rotary converter then associates the synchronous machine with the d-c machine. The losses and heating must be treated from a general point of view, since the methods of their calculation are the same for all machines.

I believe that this method of teaching electric machinery is the shortest and most logical. It gives the student a far better understanding of the phenomena in electric machines, than does the practice of treating each machine as an individual unit.

"Klydonogram" Reproduced on Golf Green by Lightning Stroke

Lightning striking the smooth wet surface of a golf green at the South Hills Country Club, Pittsburgh, Pa., burned this unusual lacey pattern into the grass. The figure was similar to that produced by positive discharges on sensitized photographic films used in the Klydonograph, an instrument for the investigation of surge phenomena. The 16 main branches of the figure varied in length radially between 61 and 70 inches. The lightning left a hole 1¼ inches in diameter and 1¼ deep at the center. P. H. McAuley (A '36) and Edward Beck (M '35) engineers of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. are shown examining the terrain after the storm

A Letter on the Kilgore Bill

From Vannevar Bush (F'24) to Senator H. M. Kilgore

My dear Senator Kilgore:

As I promised in my letter of August 18, I am now writing you a further letter in regard to S 702. It is a long letter, for I have commented not only on the bill itself, but also more broadly on the general subject, in the attempt to give you my thoughts in a constructive manner. These comments apply not only to S 702 but also to its companion bill, HR 2100, which was introduced by Mr. Patman on March 5, 1943, and was referred to the House of Representatives' committee on patents.

This problem that we both have been studying is exceedingly important. Since it may well involve the future health, comfort, and safety of this nation to an extraordinary degree, its importance warrants all of the effort which you and your committee have been devoting to it.

It has two phases. One is the appropriate organization of science and technology for the prosecution of the war. The second is the corresponding problem in times of peace.

WARTIME IMPLICATIONS

In my opinion, these two phases cannot be treated as a unit. In times of war this great democracy does many things that are aimed at a relatively brief intense effort. We centralize authority, subject ourselves to rationing and restraints, and send our sons to fight under the necessary rigors of military organization. Events have already shown that a democracy which thus girds itself for war can contend successfully with the most rigid of totalitarian states. In fact, it can overcome them, for the resourcefulness initiative, and self-reliance which are engendered in a people by the privileges of democracy, when marshalled under a temporary authoritative war organization, can surpass by far the performance of any permanently regimented people in the complexities and technicalities of modern war. We have already proved this in Africa, in the Far East, and over Europe, and we will prove it again and again as the war progresses. I trust that we as a people will never forget what we have learned and are learning during this war period.

Thus, in time of war, I believe in a centralized control, and I believe such control can appropriately be applied to science and its applications, if every effort is made in the process to preserve the independence of action of scientific and technical groups within their assigned spheres of action to the maximum possible extent. This has been the philosophy of the Office of Scientific Research and Development, and the record will show that it has been successful in its fields of development of new weapons and military medicine.

As applied to the war period, S 702 seems to have four major objectives. First of all, it would alter the existing administrative organization of scientific activities by setting up an Office of Scientific and Technical Mobilization having the powers specified in section 4 of the bill. Secondly, it would further amend the provisions of the Selective Training and Service Act of 1940, as amended, by setting up a separate procedure for the granting of occupational deferments to people having scientific or technical training and experience. Thirdly, the administrator of the Office of Scientific and Technical Mobilization would be given certain powers with respect to the requisitioning of scientific and technical facilities during the war. Lastly, the bill would vest in the Office of Scientific and Technical Mobilization very broad and far-reaching patent rights. I think that it may be helpful for you to have my comments on and reactions to each of those wartime objectives.

Administration of Wartime Scientific Activities. As I pointed out in some detail in my letter to you (dated December 7, 1942), commenting on the bill (S 2721) that you introduced at the last Congressional session, there is an adequate existing administrative setup handling the necessary scientific war activities. Under Executive Order 8807, the President granted rather broad powers to OSRD, a temporary war agency, concerning the planning, co-ordination, initiation, and support of scientific and medical national-defense research activities. These powers have been carefully scrutinized for the past several years by the Congressional appropriation committees, and the congress has seen fit to finance OSRD's operations by providing the necessary appropriations. Acting under that authority provided by the President and the Congress, OSRD has become the keystone of a closely integrated, highly co-operative organization of war research and development work for the Armed Services. That such an organization has been and is successful is best evidenced by the great confidence shown in it by the Armed Services and by the extremely important results that have been achieved.

It seems to me that it would be ill-advised and dangerous to throw a "monkey wrench" into such finely meshed machinery at this late date by such a major administrative

Vannevar Bush is president, Carnegie Institution of Washington, Washington, D. C., and director, Office of Scientific Research and Development, Washington, D. C.

As director of the Office of Scientific Research and Development, Doctor Bush is eminently qualified to analyze the wartime implications of the Kilgore Bill S 702 and its companion Patman Bill HR 2100. He is equally well qualified to analyze their peacetime implications by virtue of his achievements and standing as a scientist, engineer, educator, and administrator, for which he recently was awarded the AIEE 1943 Edison Medal.

The AIEE board of directors adopted resolutions opposing passage of these bills on June 24, 1943. This action was reported and the provisions of the bills were outlined in the August 1943 issue of "Electrical Engineering" (pages 360–1) which also carried additional comments in the "Letters to the Editor" columns (page 381). Further correspondence on this important topic is invited.

change as is reflected in S 702. Because of the inevitable disruption and confusion that would result from such a major organizational change, it seems to me that the Congress might better concentrate its efforts on remedying any flaws that you may find in our existing organization rather than attempt to superimpose an over-all organization at this late date in the war period.

Wartime Utilization of Scientific Personnel. The second major wartime change reflected in S 702 concerns the better utilization of our scientific personnel by amending the Selective Service Act. Subject to that act and all the powers and regulations of the War Manpower Commission, OSRD has mobilized a large percentage of the best qualified scientists and technicians of the country, primarily by means of the execution of contracts with educational institutions and industrial organizations whereunder specific war projects are conducted. However, OSRD's powers concerning the utilization of scientific personnel in war work have not included any authority to affect in any way the operations of the Selective Service System by controlling generally the disposition and utilization of men having scientific and technical training. The relationship of our scientific man power to the Selective Service procedure has not, in my opinion, been clearly defined, and the procedure for ensuring that men of this special training are used to full advantage in places where their talents could best further the war effort has been ineffective. It seems to me that the prosecution of modern war requires the treatment of scientific men as a special group to be specially allocated for work in the fighting services and in civilian research, and that this cannot be done adequately under the present procedures of the Selective Service System. There is no question here of shielding a special class against the rigors of war. It is rather the question of the intelligent use of a great nation's asset. The young men who make up this group should be under orders to serve where needed and, if the public interest indicates that they should remain in the laboratory rather than serve in the field, they should be retained in the laboratory. Likewise, when they are needed in the field they should be transferred there under orders to share the combat hazards with the members of the Armed Services in performing their duties. In other words, the scientific group should have their own selective service system, adapted to placing them exactly where needed.

My comments on this point are not intended to be in criticism of the efforts of the present Selective Service System because my point is directed rather to the legislative basis on which they operate. As a matter of fact, in spite of its inherent difficulty, much progress has been made on the job by the co-operation between the various governmental agencies involved. The problem is far from solved, however, and even at this late date I think that it would be advisable to enact legislation placing the matter on a firm basis. Therefore, I suggest that the Congress might well consider section 5 of S 702 along with other pending legislation affecting the operations of the Selective Service System in order to work out as soon as possible a solution to this problem that is consistent with the solution to other manpower problems.

Requisitioning of Scientific Facilities for War. Concerning that part of S 702 dealing with the requisitioning of scientific and technical facilities needed by the Government for war purposes, it seems to me that no such legislation is needed because the present patent and war-emergency laws are adequate for the purpose. Under existing legislation, the Government has the right to requisition facilities and to use patents needed for war purposes in cases where it is not possible to negotiate with the owners. Although such power is now available for use, it has been the experience of OSRD that it is necessary to exercise such powers only in the most exceptional cases. As a whole, we have found the owners of facilities and patent rights to be more than willing to turn over the use of their property to the Government for war work on a reasonable basis.

Wartime Use of Patents. The last point covered by S 702 in wartime concerns the vesting in the Government of certain patent rights. On this point, I think that it is important for you and your committee to consider the possible effects of such legislation on the prosecution of the war. Since the declaration of the national emergency on May 27, 1941, the Government has entered into thousands of contracts calling for work in connection with the development and improvement of war weapons. At least in the case of OSRD, all research and development work has been done under such contracts on a nonprofit basis, both by educational institutions and commercial organizations. In handling inventions made by commercial organizations under its contracts, OSRD has followed the lead of the Army and Navy by providing in the contracts that the Government shall receive a royalty-free license to such inventions for specified purposes and that the title to such inventions shall vest in the contractors. In a great many such cases, of course, the contractors concerned have worked for many years, spent considerable sums of money, and accumulated many patent rights before they arrived at the point of development reached at the time of the execution of their first Government contracts. Thus, work under Government contracts frequently involves only minor adaptations of past inventions made by the contractors, and in such cases the contribution to the final product attributable to the work financed by the Government is relatively insignificant. In all such cases the Government has followed the theory that it should pay reasonable royalties for the use of inventions made prior to the Government contract and should receive only a royalty-free license for developments made under a Government contract.

The theory expressed in section 7 of S 702 constitutes a radical departure from the theory heretofore followed by the Government in dealing with war contractors concerning patent rights. I think that it is important to recognize the fact that such a radical departure undoubtedly will be vigorously fought by those persons and organizations opposed to the theory that the Government should be the owner and custodian of all inventions made since May 27, 1941, under contracts or other arrangements whereby the Government has contributed "any money, credit, physical facilities, or personnel." Even though provision is made for the payment of fair and just compensation for the seizure of such property rights, there will be many who will protest that the Government has broken faith with those who have relied upon equitable contractual agreements entered into in good faith by organizations whose primary purpose has been to make more effective the prosecution of the war. It is my considered judgment that the storm of controversy that would arise upon the enactment of such far-sweeping legislation, especially from those large commercial organizations whose com-

plete co-operation and attention is vitally needed in the war program, would do irreparable harm to the united and concerted program for the development, improvement, and utilization of war weapons that is now being carried on so effectively. Therefore, I suggest that consideration of a radical departure from the present governmental system of handling patent rights at least be deferred until after the war is won and that it then be made the subject of very careful study before action is taken.

On the general question of the advisability of such patent legislation, I wish to point out that the President has appointed a Patent Planning Commission which has been working on this general problem for some time. I regard the first report of the commission (*EE, Sept. '43, pp. 423–4*) as being a valuable step toward effectuating certain advisable changes in our patent system, and I understand that the commission is now at work on a second report dealing with the problem of Government ownership of patent rights. In view of the complexity of the problem, I believe that it is advisable to await the results of the commission's study before any attempt is made to enact legislation.

My personal views concerning our patent system have been expressed before the Temporary National Economic Committee, but perhaps it will be helpful to summarize them here. In my opinion, one of the primary factors bringing about our extraordinary technical advancement and our high standard of living has been the fact that this country has had a sound patent system stemming from the Constitution. That system now needs some revision in order to make it consistent with modern conditions and to benefit from our past experience. Any such revision, however, should be made deliberately and with great care so that the fundamentals which have proved so valuable to the country over a long period of time are not injured. I believe that it is essential to the health of our industrial life for us to have a constant influx of new, small, and aggressive companies, and our sound patent system up to date has made possible the advent of such companies. Thus, it seems to me that basically our present patent system furthers the public interest.

Of course, it is inevitable that over a period of time the Government should accumulate a large number of patent rights, especially considering the present number of Government employees and Government contracts providing for such acquisition. I agree with other commentators that at the present time we have no fully adequate method of handling such patent rights for the full benefit of the public, and I am in complete sympathy with the attempts of the Patent Planning Commission to work out a uniform administration applicable to all Government agencies that will be in the best public interest. However, inasmuch as the patent-system problems cover many issues that are complicated by war conditions and are quite unrelated to the general scope of S 702, I think that the problem requires separate legislative treatment and full consideration by all the Congressional committees having jurisdiction over patent problems.

Summarizing my views on the wartime aspects of S 702, it seems to me that: (1) the proposed administrative changes are undesirable and would be detrimental to the effective prosecution of the war; (2) the proposed requisitioning power covering scientific facilities is not needed; (3) the proposed change in the Selective Service System concerning scientists and technicians should be considered carefully by all the Congressional committees studying the man-power problem; and (4) the proposed changes affecting inventions and patent rights should not be made during wartime because they would be a source of confusion and dissatisfaction that would be harmful to the war effort, but certain such proposals might profitably be referred to the Senate and House committees on patents for consideration along with other suggestions concerning the improvement of our patent system. Thus, I conclude that no overall legislation of the type embodied in S 702 is needed at this time concerning the organization of scientists in connection with the war effort.

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2. The proposed requisitioning power covering scientific facilities is not needed.

3. The proposed change in the Selective Service system concerning scientists and technicians should be considered carefully by all the Congressional committees studying the man-power problems.

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PEACETIME IMPLICATIONS

That leads me to approach S 702 from the standpoint of studying its proposals concerning the appropriate peacetime organization by the Government of the scientific affairs of the country. This aspect is fully as important as the first, especially since we are getting along reasonably well in applying science to the war effort, and it is important for the prosperity and safety of the country that equally successful relations between the Federal Government and the scientists be maintained in the years of peace to come.

You and I have in view the same end; namely, the best furtherance of science for the benefit of the country. Although we may differ in our analysis of the methods to be followed in achieving that objective, I think that the matter is of such importance that it should be studied from every angle and every shadow of thought explored in an attempt to reach the best solution. It is in what I think is a spirit of constructive criticism that I find myself in disagreement with details of the peacetime aspects of S 702 and even more strongly with the underlying philosophy upon which they are formulated. I am in agreement with other aspects of the bill, however, and I shall attempt to emphasize these and point out the means which my experience in science and Government leads me to believe will form the basis for beneficial legislation.

Before discussing the effect of the proposed legislation on different scientific groups, it seems advisable to point out that my analysis is based on the assumption that "all agencies and departments of the Federal Government," as used in section 4(*f*) of S 702, means "all agencies (of the Federal Government) and departments of the Federal Government." If a broader meaning is intended under which the power of co-ordination given to the Office of Scientific and Technical Mobilization would extend to nongovernmental agencies as well as agencies of the Federal Government, many of the comments which I shall set forth would be quite different. The question of

interpreting properly the quoted words brings up what I think is a fundamental inconsistency between the extremely broad purposes set out in section 1 of S 702 and the much more limited powers that would be given to the Office of Scientific and Technical Mobilization under section 4 in order "To effectuate the purposes of this Act, ..." It seems to me that this inconsistency should be recognized by a narrower definition of the purposes of the act.

There are three great groups of scientific and technical men in this country: those in public service, those in industry, and those in universities and nonprofit independent scientific institutions. In considering the need for central control over science by the Federal Government beyond that which existed prior to the war, it is necessary to examine and analyze these three groups separately.

Scientific Personnel in Government. We should, of course, continue scientific activities on the part of agencies and departments of the Federal Government, and the Congress should support such activities generously because there are many phases of scientific work that can best be done by men in the Government service. As a nation we can be proud of the accomplishments of many of our Government laboratories, such as the Bureau of Standards, the Public Health Service, several of the Department of Agriculture laboratories, and so on. In the past there have been several proposals to centralize all government scientific work in a single department, possibly making this a new Department of Science with cabinet representation. This idea is attractive to many, especially as it would seem to give an added recognition and support to science in Government departments. There are, however, several disadvantages to such a full unification of governmental scientific effort that should be weighed carefully before any such move is effected.

The greatest difficulty would lie in divorcing each separate Government scientific effort from close association with the department most interested in its work. For example, the scientific work of the Bureau of Entomology and Plant Quarantine, the Bureau of Agricultural Chemistry and Engineering, and other such bureaus, is almost inseparably connected with the work of the Department of Agriculture as a whole. Similarly, the Geological Survey derives strength by being a part of the Department of the Interior. Examples of this sort could be multiplied. I am sure that centralized control by a new independent agency of all scientific work in Government departments would be strongly resisted. Certainly the War and Navy Departments would insist that they control absolutely the secret work on new weapons which they conduct in their own laboratories in times of peace, much as they might be willing to supplement their own activities by requesting and receiving help from the universities, industry, and other governmental laboratories. Therefore, I have come to the conclusion that it would be difficult to gather all science activities of the Government into one organization without serious sacrifice. As a matter of fact, I judge that you have reached the same conclusion because I do not find any such complete integration of governmental research in the bill.

In section 4(*f*), however, I do find a provision for the co-ordination of the governmental research activities of the various Federal agencies and departments. This, I judge, is not intended to imply either power to direct or power to control, independent of the heads of departments and agencies, but rather a central scientific clearing house set up for the interchange of data and plans in order to prevent overlapping and to facilitate that cross-fertilization of scientific effort which is often highly valuable. I have long thought that a body set up for this explicit purpose might perform a very useful function. It should certainly have joined with it an advisory scientific group, drawn on a voluntary basis from the best-qualified scientific personnel of the country. There has been an increasing tendency in recent years, much to be welcomed, for individual bureaus to establish such advisory groups for their own purposes. They have often acted as reviewing bodies for the heads of the departments concerned, and their influence has been important and beneficial. A central body would form a desirable linkage between these.

In passing, allow me to present a thought in this connection which is not a part of the bill, but which is allied with this matter. I have often wondered that the Congress and its committees do not avail themselves more freely of the advice of the scientists of the country. True, the Congress has available all of the scientific men in the executive departments for aid when it approaches a problem of scientific nature, but it does not often call upon more widely constituted groups. The departments and agencies often seek advice in this manner, turning usually to the National Academy of Sciences, which was constituted by Congress for this explicit purpose. Some agencies, notably the National Advisory Committee for Aeronautics, include scientific men in their organizations who serve on a voluntary basis, and I think that all will agree that this has worked well in the case of the NACA. But the committees of Congress themselves seldom use the scientists of the country directly, much as these men are willing thus to contribute their services voluntarily to their country's welfare and interests, and I feel that this could be done to advantage.

It may well be asked: How does one select scientists for this and similar purposes, in order to be sure of their ability and disinterestedness? Such a question is pertinent to a discussion of the bill, for I feel that its provisions for the selection of the necessary scientific personnel are not adequate for ensuring the services of men of the necessary caliber.

There is only one sound criterion for estimating the standing and capability of a man of science, and that is the evaluation of the way in which he is regarded by his colleagues in his profession. If there were only one way of doing this, perhaps it might not suffice, but there are many. Membership in scientific societies of standing is important, wherever such membership is dependent upon evaluation and election. Recognition by learned bodies is a guide. There are even lists of outstanding scientists, prepared by taking ballots among scientists themselves. Some of the scientific bodies, notably the National Academy of Sciences, have the recognition of the Congress in their charters. The American Association for the Advancement of Science, through a carefully prepared system

So far as Government scientists are concerned, the bill does not now provide adequately for the correlation of their efforts, and it would be inadvisable to extend the bill to the point where unitary control of all governmental research would be exerted, but there is an opportunity in this field for beneficial correlation of effort.

of representation, integrates the large membership in very many scientific organizations throughout the country. It seems to me that some of this existing machinery should be utilized in the procedure of selecting representative scientists for a governmental purpose in order to select representative men having the confidence of scientists generally. It can safely be assumed that men selected for eminence in science by scientists themselves will also generally be disinterested, for men can very seldom rise to real prominence in science in the estimation of their colleagues unless they place science itself first in the ordering of their professional careers.

The general idea of having various units in an industry competing on the basis of which one can supply the public with the best goods at the lowest cost is hard to improve upon in theory, and in general it has worked well in practice. The industrial laboratories are an essential part of this process, and they should be subjected to as little centralized control as possible.

In reviewing the bill, and in thinking of postwar scientific organization generally, I believe this point is important, and it seems to me that the present provisions in the bill for securing the services of scientists in the contemplated organization are not designed to secure the best men possible. Furthermore, these same comments apply to the membership of the so-called National Scientific and Technical Board and the advisory committee.

My summary, then, so far as this first group of Government scientists is concerned, is that the bill does not now provide adequately for the correlation of their efforts and that it would be inadvisable to extend the bill to the point where unitary control of all governmental research would be exerted, but that there is an opportunity in this field for beneficial correlation of effort.

Industrial Scientific Personnel and Laboratories. The second group of scientists and technical men to be considered are in the research laboratories of industrial organizations. There are over 2,000 such laboratories, large and small, and their work is of great importance, particularly in view of the growing tendency in this country among large industrial laboratories to carry on research of a fundamental scientific nature and to publish the results.

During the war these industrial laboratories have been of great importance in the development of weapons, working under contracts with the Army, the Navy, and the Office of Scientific Research and Development. As far as the latter is concerned I can testify that we have had effective co-operation from the group at every point, that they have accomplished results of great importance, and that with negligible exceptions they have decidedly placed the interests of the country first and have not allowed their commercial interests to interfere with their contributions to the general cause. I have already discussed the provisions of the bill that would alter in several ways the relationship of these laboratories to government in the prosecution of research on new weapons during the war, and I have noted that I do not feel that new legislation is needed for this purpose.

The position of this group of scientists under the bill during the postwar period is hence the primary point for consideration. As I interpret the bill, they would not be greatly affected because most of the clauses which would alter their relationships are limited to the duration of a state of war. Presumably, the funds of the new Office would be used, in times of peace, either to construct and operate new governmental laboratories or to utilize the facilities of existing laboratories under contract. While some industrial units might elect to operate their laboratories in that way, the chances are that in time of peace most industrial units would not wish to perform any substantial amount of their scientific work under government contract, especially considering some of the provisions in S 702 concerning patent rights. Furthermore, I doubt if these industrial laboratories would accept in peacetime contracts consistent with the OSRD nonprofit theory as applied to research and development contracts. The alternative of including a large profit under the contracts, in the attempt to enlist the voluntary participation of these laboratories in a peacetime plan, is certainly not an attractive procedure.

As a matter of general policy, I do not believe that it would be wise for Government to attempt to control the operations of these industrial laboratories, as might possibly be implied in the purpose specified in section 1(4), although presumably not within the scope of the powers and duties that would be given the new Office. The industrial laboratories form an integral part of the industries with which they are associated, and form a part of the mechanism by which units in a single industry, and entire industries, compete with one another. Moreover, their particular part in such competition is directed explicitly toward the provision of better products for public consumption. The maintenance of such an atmosphere of competition, as opposed to close government regulation of monopolistic combinations engaged in manufacturing the products which the public needs, has been the philosophy behind a large amount of legislation during the past generation, and I believe that such a philosophy is in the public interest. Undoubtedly our laws regarding trade combinations can be improved, or at least clarified, in order to render the system more fully beneficial; but the general idea of having various units in an industry competing on the basis of which one can supply the public with the best goods at the lowest cost is hard to improve upon in theory, and in general it has worked well in practice wherever it has been truly operative. The industrial laboratories are an essential part of this process, and I feel that they should be subjected to as little centralized control as possible.

Federal subsidy of the independent science of universities and other institutions may be beneficial, and it may be necessary in the years to come if we are to preserve that preeminence in science as a nation which is essential to our progress. However, the support should be divorced from governmental control of the scientists and laboratories themselves, or it will stifle rather than expedite their true accomplishments.

Scientific Personnel in Universities and Institutions. That brings us to a consideration of the proposed postwar effects of the bill on the third class of scientists, namely, those in universities and nonprofit independent scientific institutions, and it seems to me that this group may be primarily affected.

In time of war it seems to me that the public interest demands that this group should be closely organized in order to apply its accumulated scientific knowledge to the

direct needs of the Armed Services for developing new weapons and equipment and for meeting the needs of military medicine, and this organization has been accomplished by the Office of Scientific Research and Development, a war agency. Although such organization is necessary in time of war, it seems to me that in time of peace the scientists in this group should be given a maximum of freedom and a minimum of control from any source. Therefore, I think that it would be a mistake to attempt to control their activities through a federal agency.

Since science flourishes to the greatest degree when it is most free, we should bend our peacetime efforts not to perpetuate any of the necessary wartime controls we have created for our defense, but rather to return the maximum of independence to our scientific institutions and our scientific men.

Of course, in view of the fact that many private institutions may be unable to finance an appreciable amount of scientific research activity after the war, it may be advisable or even necessary for such institutions to look to the federal and state governments for financial support. Our past experience in this country has shown us that it is possible for such governmental financial support to be given without being attended by stifling control, but the factual situation may be different after this war. For example, it seems to me that the high scientific standards of which quite a few state-financed institutions can be proud are attributable in no small part to the fact that up to the present time such institutions have been competing against privately endowed institutions with exceptionally high standards which were in a position to attract very outstanding scientists who felt that their efforts in state institutions were too closely controlled. If such competition is still present after the war, I can foresee many advantages and few disadvantages of Federal financial support of the research activities of scientists in universities; if, however, there is no such strong competition, we must be careful lest federal financial support carries with it features of undesirable control.

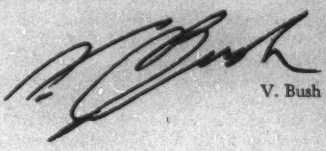
Thus, I think that federal subsidy of the independent science of universities and other institutions in this country may be beneficial, and it may in fact be necessary in the years to come if we are to preserve that pre-eminence in science as a nation which is essential to our progress. But, unless we have the wisdom to extend support wisely, it may do much more harm than good. If federal support is to be given, strenuous efforts will be necessary to ensure that it furthers the work of the best and most brilliant scientific minds, and does not merely increase the bulk of mediocre work. And the support should be divorced from governmental control of the scientists and laboratories themselves, or it will stifle rather than expedite their true accomplishments.

The presence of a great body of highly able scientific men in this country has recently been an indispensable asset in time of danger. We must be sure that it is again present if we are again threatened, and science of the highest type flourishes best when it seeks its own objectives and pursues its own uninhibited ways. If we perpetuate in this country in the years to come a scientific atmosphere and body of men of the caliber that we now have, I will fear no threat from any source, for in time of need they will again respond, they will again direct their full energies in a patriotic effort, working under a closely unified and controlled program of the application of science in the prosecution of war, and they will thus do their full part in the protection of this country.

In conclusion, I wish to point out that there is another aspect of this whole subject of the furtherance of science. It extends beyond the mere application of the fruits of science to improve the comfort of the people, and it is on a more fundamental basis even than the safety of the country to external danger. The broad object of science is to increase the knowledge and the understanding of man. It aims at extending his grasp of the environment in which he lives, and his appreciation of the vast and intricate system of nature by which he is surrounded, from the study of the remote stars to the constitution of the smallest atom. We need science for this as well, so that as we live we may derive satisfaction by growing in knowledge.

Since after many years I have come to the realization that science flourishes to the greatest degree when it is most free, I feel strongly that, when peace comes, we should bend our efforts, not to perpetuate any of the necessary wartime controls which we have created for our defense, but rather to return the maximum of independence to our scientific institutions and our scientific men, wherever they may be located.

Very sincerely yours,



V. Bush

Societies Oppose Kilgore Bill

Since the board of direction of the American Society of Civil Engineers studied bill S 2721 at the request of Senator Kilgore and expressed unanimous disapproval of its provisions on February 19, 1943, many other scientific and engineering societies as well as AIEE have crystallized their opinions in resolutions addressed to Senator Kilgore. The organizations which have made formal representation thus far have revealed unanimous dissent with the proposed measures of the original bill, the revised bill S 702, and its companion bill HR 2100. ASCE expressed additional adverse criticism of S 702 in April 1943. AIEE adopted its resolution opposing the bills in June; the war policy committee of the American Institute of Physics publicized its opposition in July; the Institute of Radio Engineers and the American Association for the Advancement of Science voiced their objections in August; and the council of the American Society of Mechanical Engineers joined the opposition in November. The Society of Automotive Engineers has referred the matter to its local sections for discussion and individual action.

Mathematical Training for Young Engineers

C. A. POWEL
FELLOW AIEE

A QUESTION frequently raised is how much mathematics does industry expect of the students graduating from our colleges. The answer depends largely on the capability of the individual student and how the particular enterprise he has joined intends to use him.

Basically, mathematics should not be taught to engineers as an end in itself. Engineers are essentially practical people trying to produce something very tangible. If they have to use mathematics at all, it is purely as a tool. Educational courses should be set up with this in mind and with the realization that the student's ability to visualize the mathematical processes in the light of their physical counterpart is the thing that will make him useful to industry later on. This is not a new idea, and some excellent textbooks have been written with just this in mind. For instance, Doherty and Keller's book, "Mathematics of Modern Engineering," is typical and adequately fulfills this purpose.

Mathematics should be taught to the young engineer, not as an end in itself, but as a tool to be used to gain his objectives. The ability of the young engineer to use mathematics successfully in his work rather than the extent of his actual knowledge in this field is a gauge of his usefulness to industry.

At Westinghouse Electric and Manufacturing Company we receive from the colleges every year a large number of engineering students. Most of them go into design and production work that does not require advanced mathematics. For this reason there does not seem to be much justification for burdening undergraduate courses with much mathematics as a requirement. Most of the young engineers we take on have adequate mathematical preparation.

On entering industry, the young engineer will find that the work expected of him can be separated into three levels:

The first or basic level involves the utilization of information already accumulated and being used currently by his coworkers. It covers the use of standard data, formulas, and engineering memoranda, all well-tried and carefully checked, and requires a moderate amount of training and ease in handling figures and equations with accuracy.

The second or intermediate level of engineering activity involves the study of current scientific literature in order to extract new methods of analysis and technique. The articles in general will be written by specialized engineers, physicists, and mathematicians, and will require serious application and good general training. Success in this direction requires mathematical manipulation of a somewhat higher order.

The third and highest level of engineering involves the original solution of problems encountered by the individual himself. This means charting new courses and requires a fundamental knowledge of mathematical analysis of a much higher degree than the first two levels.

C. A. Powel is manager, headquarters engineering departments, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Industry expects the young engineer to be trained to the point where he can absorb existing information and keep abreast of current progress in his chosen field. This requires that in his undergraduate years he should have mastered geometry, college algebra, trigonometry, differential calculus, and integral calculus. There should also be an elective in differential equations for those students who are mathematically inclined. Any continuation beyond undergraduate work requires differential equations. In the Westinghouse graduate program offered in co-operation with the universities of Pittsburgh, New York, Stevens Institute, and so forth, we require a full year's work in differential equations as a prerequisite for such advanced courses as engineering mathematics, basic concepts of physics, and so on.

To enter the third level involving original work, more training than is provided in an undergraduate course is required. This may be obtained as postgraduate work in the university leading to a master's degree or a doctor's degree, or it may be obtained through personal effort in industry itself.

Students who are candidates for the master's degree usually are possessed of greater analytical ability and have greater natural aptitude for investigational work. They are, therefore, better qualified to pursue training in higher mathematics. Such students should be required to take, besides the year's course in differential equations, an additional course selected from such subjects as functions of a complex variable, vector analysis, Fourier integrals, and Heaviside's operational calculus.

For the doctor's degree the student should have, in addition to the requirements for the master's degree, at least two of the previously mentioned mathematical subjects, and also a rigorous course in the mathematical theory of electricity using Maxwell's equations as a basis. A course of this type is covered in Becker's translation of Abraham's book, entitled "Electricity and Magnetism," which is particularly good, because it emphasizes the physical significance of the mathematical relations.

Many large industrial establishments in conjunction with nearby colleges and universities offer opportunity for advanced study such as the Westinghouse graduate courses after the student has entered industry. In this respect, there is room for improved co-operation between the colleges in the matter of recognizing one another's credits, and particularly in waiving the requirement of one year's residence before the granting of a degree. We find that frequently a student is not able

to obtain an advanced degree because, when he is transferred to a new location, his credits previously obtained elsewhere are not honored.

The exact nature of the advanced study will depend a good deal on the type of work in which the student is interested. These observations apply principally to electrical engineers, who form the greater part of the engineering organization in the Westinghouse company. But some familiarity with the mathematics used in related fields is a decided asset. For example, a power engineer working on circuit theory may find much helpful information in the work already carried out in the communication field. Likewise, we frequently run across cases of mechanical equivalents being used to solve electrical problems, and vice versa.

We have found a pronounced need for a tie between physics and mathematics. A student may know the physical laws involved in some phenomenon and he may be able to solve differential equations, but the difficulty lies in setting up the equation correctly, which is perhaps the most important step in the whole solution.

However far the student proposes to go in college—bachelor, master, or doctor—the point to remember is that his plan is to become an engineer, and a major part of his time cannot be devoted to mathematics. If he can be made to understand mathematics as a tool and be taught to develop it further in after life as he finds its use necessary to attain his main objective, he will have received everything from mathematics that industry can expect of the colleges.

Magnesium From Sea Water

The increased importance of the production of magnesium metal has become apparent since the war. For one thing, wartime contingencies have given a great acceleration to the use of the lighter metals. Besides its importance as a metal for construction where lightness is paramount, as in the fabrication of both airplane and engine parts, magnesium is the major constituent of incendiary bombs and flares used to illuminate war operations and aerial photography.

Magnesium is the sixth most plentiful element in the earth's crust, and the fourth most plentiful metal. It is never found free in nature as a metal but always combines with oxygen or chlorine, or as a carbonate, sulphate, or silicate. The largest concentrations of the mineral exist in brucite and magnesite, found in limited quantities in the United States, and in the almost unlimited quantities of dolomite, serpentine, and olivine found in this country. It is from these minerals that the metallic magnesium produced industrially has been reduced.

Sea water is the greatest reservoir of the raw material, which is contained therein as magnesium chloride or magnesium sulphate. But the concentration of magnesium is small—about 0.13 per cent—and it would require about 200,000 gallons of sea water to produce a ton of magnesium if all the magnesium could be recovered. Although it is free, and although it has been used as a source for magnesium salts and magnesium metal for several years in the laboratory, production of metallic magnesium from other sources heretofore has been able to compete with that from sea water because of other factors, including materials, plant locations, and power costs.

Recently, however, The Dow Chemical Company, Midland, Mich., began operating a large plant in Texas using sea water for this purpose, the first of its kind in the United States. The process used is a modification of the one originally developed by Herbert H. Dow, founder of the Dow Company, and the man generally credited with the development of the magnesium industry in the United States.

In this process, the sea water is first treated with lime produced by calcining oyster shells and hydrating the lime so produced. This sea-water treatment results in the precipitation of magnesium hydrate, which is allowed to settle in large Dorr thickeners and then further dewatered by filtration. The magnesium-hydrate cake from the filters is then brought into reaction with hydrochloric acid, and the magnesium chloride thus formed is concentrated, purified, and dried. In this state it is used as a feed for the magnesium-producing cells. In the magnesium cells electrolysis of the magnesium chloride results in the formation of magnesium metal and a mixture of air, chlorine, and hydrochloric acid in low concentrations. The acid and chlorine, in turn, are used in the production of hydrochloric acid, which is then used to neutralize additional magnesium hydroxide.

In addition to the plants which the Dow company is building and already has in operation, two other manufacturers in the United States are utilizing the Dow electrolytic cells for production of magnesium metal. These are the Diamond Alkali Company, operating in Ohio, and the International Minerals and Chemical Corporation in Texas. In each of these plants the magnesium-chloride feed for the cells is made by a different process. At the plant being operated by International, a part of the magnesium chloride is produced as a by-product from the manufacture of potassium sulphate, utilizing langbeinite and muriate of potash, both of which are produced at the company's mines near Carlsbad, N. Mex. Basic Magnesium, Incorporated, has installed a plant in Nevada, which utilizes the electrolysis of anhydrous magnesium chloride.

Abstracted from "Magnesium," by Paul D. V. Manning, *Mining and Metallurgy*, August 1943.

INSTITUTE ACTIVITIES

Revisions Made to "Simplified Calculation of Fault Currents"

A report on a simplified procedure for the calculation of short-circuit currents, published as "Simplified Calculation of Fault Currents" (*EE, Oct. '42, pp. 509–11; and AIEE Trans., '42, pp. 1133–35*), was sponsored and prepared by the AIEE committee on protective devices as one of its projects for 1940–42. The method described had been given trial use for over a year and was found to be generally satisfactory for the purpose intended.

A recent review of the procedure, however, revealed the need for certain modifications in order to improve and bring the report up to date. The suggested revisions, pertaining particularly to fuses and to fault-current calculations for generating-station breakers, have been made and approved by the committee on protective devices. They are embodied in the following report, presented with an amplification of the reasons therefor by J. B. MacNeill, chairman of the committee.

CALCULATIONS FOR CIRCUIT BREAKERS

In the original paper for breaker application at generator voltage, a permissive additional factor up to 20 per cent was recommended for such applications. Subsequent investigations of the characteristics of various systems pointed the way to replace this variable factor by definite ones. It has been found that for systems where the three-phase-fault kilovolt-ampere at the generator bus voltage does not exceed 500,000 (before the application of multiplying factors), no additional multiplying factor is required. For calculations exceeding 500,000 kva a definite additional factor of 10 per cent must be added to the several classes of breakers, all as set forth in the revised section A-2 of Table I.

CALCULATIONS FOR FUSES

Under section D-2 of the original table a factor of 1.2 was recommended for fuses of 15 kilovolts or lower, with interrupting ratings not exceeding 3,000 amperes.

This limitation was arbitrary and based on the limits of design at the time the paper was prepared. Improvement in design of low-voltage fuses has made this limitation a hardship on both the users and manufacturers of such fuses. After careful consideration, it was thought that a more logical basis would be the introduction of a X/R ratio in the calculation, using the entire X value from source of power to the fuse location, but the R value only from the fuse back to the first primary substation. The error in neglecting the remainder of R is negligible, and the difficulty in obtaining rigorous values was not commensurate with increase in accuracy obtained. If the X/R ratio is *less than 4*, the lower multiplying factor of 1.2 is permissible; otherwise the factor of 1.6 should be used. Although it was recognized that the same line of reasoning could be applied to higher-voltage fuses which are not current limiting, a survey of many cases indicated that the majority of these cases would fall in the 1.6 class and, therefore, no change is recommended for general use.

Specific mention has been given to current-limiting fuses. *For all voltages the mutliplying factor will be 1.6.* This is so because the basis of such fuse ratings is given on an unsymmetrical current value equal to 1.6 times the symmetrical current. Since the symmetrical value gives the most severe duty to the fuse, it is obvious that the 1.6 factor must be used for all current-limiting fuses.

With the aforementioned points in view, the following directions for changes are given.

At the beginning of the fourth paragraph under the subheading, "Procedure," change the wording to read thus:

Fuses are rated on total current, and, as the time durations involved are very short, their required interrupting capacity should be based on the total rms current at one-half cycle, using subtransient reactances for both synchronous and induction machines. Two cases should be considered:

1. At 15,000 volts or below, except for current-limiting fuses, when the fuse located is remote from generating stations or primary substations (that is, X/R is less than 4) multiply by 1.2. In determining the X/R ratio, it will be sufficiently accurate to use the resistance between the generating or primary substation bus and the fuse location only. The reactance all the way back to the source should be included, however.

2. In all other cases, including current-limiting fuses, regardless of voltage, multiply by 1.6.

NATIONAL • • • •

Official Nominees Announced for 1944–45

C. A. Powel, manager, headquarters engineering departments, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., was nominated for the AIEE presidency for the year 1944–45 by the national nominating committee at its meeting in New York, N. Y., January 25, 1944. Others named on the official ticket of candidates for the Institute offices that will become vacant August 1, 1944, are:

For Vice-Presidents

R. T. Henry, assistant chief electrical engineer, Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y. (North Eastern District, number 1).

J. F. Fairman, assistant vice-president, Consolidated Edison Company of New York, Inc., New York, N. Y. (New York City District, number 3).

M. S. Coover, professor and head of department of electrical engineering, Iowa State College, Ames, Iowa (Great Lakes District, number 5).

R. W. Warner, professor and head of department of electrical engineering, University of Texas, Austin, Tex. (South West District, number 7).

C. B. Carpenter, assistant chief engineer, Pacific Telephone and Telegraph Company, Portland, Oreg. (North West District, number 9).

For Directors

P. L. Alger, staff assistant to vice-president in charge of engineering, General Electric Company, Schenectady, N. Y.

M. J. McHenry, director of sales promotion, Hydro-Electric Power Commission of Ontario, Toronto.

D. A. Quarles, director of transmission development, Bell Telephone Laboratories, Inc., New York, N. Y.

For National Treasurer

W. I. Slichter, professor emeritus of electrical engineering, Columbia University, New York, N. Y.

In Table I under section *A* subheading, change to read as follows:

Multiplying Factor	Reactance Quantity for Use in X_1		
	Synchronous Generator	Synchronous Motor	Induction Machine
2. Special case for breakers at generator voltage only For short-circuit calculations of more than 500,000 kva (before the application of any multiplying factor) fed predominantly direct from generators, or through current-limiting reactors only.			
Eight-cycle or slower (*f*) breakers.....1.1 Five-cycle breakers.....1.2 Three-cycle breakers.....1.3 Two-cycle breakers.....1.5	Subtransient*	Transient	Neglect

In Table I under section *D* subheading, change to read as follows:

Multiplying Factor	Reactance Quantity for Use in X_1		
	Synchronous Generator	Synchronous Motor	Induction Machine
D. Fuses 1. At 15,000 volts, or below, except for current-limiting fuses when the fuse is located remote from generating stations or primary substations (that is, X/R is less than 4).....1.2 2. All other cases, including all current-limiting fuses regardless of voltage.....1.6	Subtransient	Subtransient	Subtransient

f • Refer to footnotes with original table.

Future AIEE Meetings

North Eastern District Meeting
Boston, Mass., April 19–20, 1944

Summer Technical Meeting
St. Louis, Mo., June 26–30, 1944

Pacific Coast Technical Meeting
Los Angeles, Calif., Aug. 29–Sept. 1, 1944

The nominating committee, in accordance with the constitution and bylaws, consists of 15 members, one selected by the executive committee of each of the ten geographical Districts, and five selected by the board of directors from its own membership.

The following members of the committee were present at the meeting:

Orin A. Demuth, Portland, Oreg.; A. H. Frampton, Toronto, Ont.; R. C. Gorham, Pittsburgh, Pa.; J. Elmer Housley, Alcoa, Tenn.; Arthur L. Jones, Denver, Colo.; C. H. Kraft, St. Louis, Mo.; C. M. Laffoon, East Pittsburgh, Pa.; Everett S. Lee, Schenectady, N. Y.; K. B. McEachron, Pittsfield, Mass.; J. A. Northcott, Jr., Notre Dame, Ind.; C. S. Purnell, New York, N. Y.; B. L. Robertson, Berkeley, Calif.; E. W. Schilling, Bozeman, Mont.; W. R. Smith, Newark, N. J., and H. H. Henline, secretary, New York, N. Y.

The constitution and bylaws of the Institute require publication in *Electrical Engineering* of the nominations made by the national nominating committee. Provision is made for independent nominations as indicated in the following excerpts from the constitution and bylaws:

Constitution

Section 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the bylaws; such petitions for the nomination of vice-presidents shall be signed only by members within the District covered.

Bylaws

Section 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with article VI, section 31 (Constitution), must be received by the secretary of the National Nominating Committee not later than March 25 of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with article VI of the Constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

BIOGRAPHICAL SKETCHES OF NOMINEES

To enable those Institute members not personally acquainted with the nominees to learn something about their engineering careers and their qualifications for the Institute offices to which they have been nominated, brief biographical sketches are scheduled for inclusion in the "Personal" columns of the March issue.

Subcommittee Reviews Scope of AIEE Technical Committees

A joint subcommittee on adequacy of coverage of electrical engineering field by present technical committees has been appointed by the AIEE technical program committee in response to the question referred to it by the board of directors, of whether the present committees offer sufficient coverage to the fields expanding because of wartime developments. If necessary the subcommittee is expected to recommend creation of new technical committees.

F. A. Cowan (M '29) chairman of the technical program committee has assumed the chairmanship of the new subcommittee. Choice of subcommittee members was made with a view to securing representation from those fields which are expanding rapidly and obtaining proper co-ordination with other committees. Members selected are: T. B. Holliday, air transportation; H. A. Affel, radio and ultrahigh frequency; S. B. Ingram, electronics; J. H. Lampe, electric welding; John Grotzinger, industrial power applications; W. N. Zippler, applications to marine work; F. E. Harrell, electrical machinery; D. C. Prince, planning and co-ordination; J. R. North, A. C. Monteith, standards; P. L. Alger, member at large.

Award of Fortescue Fellowship Postponed for 1944–45

Because of conditions imposed by the war, no meeting of the Fortescue Fellowship Committee will be held and no award will be made for the year 1944–45. A motion to this effect was approved by the members of the committee with the understanding that the funds available would be impounded.

The Fellowship was established in 1940 under the sponsorship of the AIEE as a memorial to Charles LeGeyt Fortescue (A '03, F '21) in recognition of his valuable contributions to the electric-power industry. A trust fund of $25,000 has been set up for this purpose by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., with which Doctor Fortescue was associated throughout his professional career. The income is used to provide fellowships of $500 or more to candidates selected annually by the committee.

Only once has the Fellowship been awarded; the appointment was made for 1940–41 to Norman Z. Alcock, Kingston, Ont. Successive annual awards have been postponed, because the war has absorbed the activities of most of the eligible candidates.

SECTION • • • • •

Milwaukee Technical Discussion Groups Enter Fourth Year

The technical discussion groups of the Milwaukee Section have begun their fourth successful season of highly specialized meetings, according to a report from Carl J. Fechheimer, group co-ordinating chairman. Formation of the groups in 1940 grew out of the recognition that there are widely diversified industries in and about Milwaukee and that a forum for the exchange of ideas and experiences beyond the scope of general-subject monthly Section meetings would be of great value to the specialists.

Three technical groups were organized originally: electrical machinery, power applications and control, and electronics. This year a fourth group on basic sciences was merged with the others; each of the original three devotes one of its meetings during the season to basic sciences. Regular monthly Section meetings have continued with topics of a general nature.

The year's activities for all the groups are correlated by the co-ordinating chairman and the executive officers of each group, who meet at the beginning of the season to determine the calendar of meetings, tentative subjects, and, when possible, the names of the speakers. From four to six meetings are held for each group during the year, with an average attendance of 38. The lecturer usually is a local engineering specialist who talks on his chosen subject for about an hour before turning the meeting over to informal discussion.

PERSONAL • • • •

F. P. Ogden (M '28) vice-president, Mountain States Telephone and Telegraph Company, Denver, Colo., has been elected president. Mr. Ogden, who was born in Sherman, Ky., in 1887, was graduated from the University of Kansas in 1911 and was employed as student engineer by the Missouri and Kansas Telephone Company, Kansas City, Mo. He served as district traffic engineer in Topeka, Kans., before entering the employ of the Mountain States company in 1914 as clerk. During 1915 and 1916 he was district traffic chief in Butte, Mont., becoming division traffic superintendent in Helena, Mont., in 1917 and in Salt Lake City, Utah, in 1921. He was made general toll supervisor in 1922 and general traffic manager in 1923. In 1938 he was appointed vice-president. **R. W. Lindsay** (A '35, M '38) formerly chief engineer succeeds Mr. Ogden as vice-president. Mr. Lindsay received the degree of bachelor of science from the University of Colorado in 1915 and entered the employ of the Mountain States company as draftsman. From 1917 to 1922 he was construction engineer. After serving as outside plant engineer's assistant from 1922 to 1926, and engineer of methods and materials from 1926 to 1928, he was made outside plant engineer in 1928. He became assistant chief engineer in 1933 and chief engineer in 1934. **H. E. Jones** (A '28, M '41) formerly equipment and building engineer, advances to the position of chief engineer vacated by Mr. Lindsay. Mr. Jones was associated with the Mountain States company first from 1905 to 1923. During this period he was engaged in outside plant work until 1908 when he became wire chief and district plant chief. In 1910 he was shifted to central office installation and in 1914 became plant chief. From 1917 to 1923 he was assistant equipment engineer. He served as maintenance engineer for the New England Telephone and Telegraph Company, Boston, Mass., from 1923 to 1926, and for the American Telephone and Telegraph Company, New York, N. Y., in 1926 and 1927. In 1927 he rejoined the Mountain States company as maintenance engineer and in 1940 was appointed equipment and building engineer.

H. C. Gardett (A '07, F '41) recently retired chief electrical engineer, and general manager of the Los Angeles (Calif.) Bureau of Power and Light has been appointed consulting engineer for the city's Department of Water and Power which has absorbed the Bureau of Power and Light and the Bureau of Water Works. Mr. Gardett received the degree of bachelor of science from the University of California in 1904 and since 1911 has been employed by the City of Los Angeles. From 1911 to 1917 he served as assistant electrical engineer in the Bureau of Los Angeles Aqueduct and in 1918 was transferred to the Bureau of the Department of Public Service where he had charge of the design and construction of all generation and transmission facilities. He was chosen head of the design and construction division of the Bureau in 1930. He was given the additional duties of assistant chief electrical engineer and general manager in 1938 and appointed chief electrical engineer and general manager in 1940. **R. R. Robertson** (M'25) formerly design and construction engineer for the Bureau of Power and Light, has been named chief electrical engineer and deputy general manager of the Department of Water and Power. He has been associated with the discontinued Bureau since 1912. Previously he had been employed by the Isthmian Canal Commission, Panama, from 1907, when he graduated from Purdue University, until 1912. **C. P. Garman** (A '23, M '26) formerly assistant engineer of design, Bureau of Power and Light, has been made deputy general manager of the power system. Mr. Garman joined the Bureau's staff in 1920 as junior electrical engineer.

E. S. Fields (A '20, F '29) formerly manager of the electric department, Cincinnati (Ohio) Gas and Electric Company, has been made vice-president. Born in Kentucky in 1897, in 1918 as maintenance electrician and operator Mr. Fields joined the Union Gas and Electric Company which was consolidated in 1936 with the Columbia Gas and Electric Company as the Cincinnati Gas and Electric Company. Remaining with the Union company until 1926 he advanced to the positions of chief electrician in 1920, assistant engineer in 1922, and assistant electrical engineer in 1924. After an association with the Columbia Engineering and Management Corporation, Cincinnati, during 1926 and 1927 as assistant electrical engineer and electrical engineer in charge of design, he returned to the Union company in 1929 as manager of the electrical department and continued in that position with the Cincinnati Gas and Electric Company. **D. S. Brown** (A '21, M '36) formerly manager of electrical production has been named vice-president in charge of that operation. Graduating from the University of Cincinnati in 1920 with the degree of electrical engineer, Mr. Brown joined the Union Gas and Electric Company as assistant superintendent of production. He was made superintendent of production in 1923 and finally manager of production in 1929.

W. I. Whitefield (A '19, M '25) formerly assistant division manager, Appalachian Electric Power Company, Roanoke, Va., has been appointed division manager. He has been associated with the company since 1915 as power engineer, superintendent of lighting and power, district manager, and assistant division manager. **J. W. Hancock** (A '10) formerly division manager retires from his position to assume an advisory position and directorship with the company. Mr. Hancock first joined the company's predecessors, the Roanoke Electric Light and Power Company and the Roanoke Street Railway Company in 1895, as accountant and cashier. He became superintendent in 1899, and general manager in 1900. From 1913 to 1927 he also was general manager of the Lynchburg (Va.) Traction and Light Company. In 1926 when the Appalachian company was formed he was named division manager. Mr. Hancock served in the Spanish–American War and is a member of several historical societies and of the Sons of the American Revolution.

E. J. Rutan (A '20, M '29) formerly senior engineer, Chemical Construction Corporation, New York, N. Y., is partner and vice-president in the recently formed consulting engineering firm of Rutan and Snead, Inc., New York. Mr. Rutan, who holds the degree of mechanical engineer from Cornell University, terminated a 23-year association with the testing department of the Consolidated Edison Company of New York, Inc., in 1942 when he joined the Chemical Corporation. He has served on AIEE committees as well as on committees of the American Society for Testing Materials and the American Standards Association. **E. W. Starr** (A '28, M '36) assistant professor of electrical engineering, Cooper Union, New York, is also a member of the new firm. Professor Starr, a graduate of Cornell University, previously taught at that institution and at Worcester Polytechnic Institute. He has also been connected with the American Steel and Wire Company and the General Electric Company, Schenectady, N. Y.

H. H. Plank (A '41) formerly assistant to the vice-president, United Gas Improvement Company, Philadelphia, Pa., has been appointed assistant to the vice-president and general manager of the Delaware Power and Light Company, the Delaware Coach Company, and its subsidiaries. After graduating from Clarkson College with the degree of bachelor of science in electrical engineering in 1917, Mr. Plank entered an apprenticeship course in public-utility operation with Henry L. Doherty and Company, Toledo, Ohio, and completed the course in 1920 when he returned from military service in World War I. From 1920 to 1922 he was industrial power engineer for the Syracuse (N. Y.) Lighting Company. In 1922 he joined the United Gas Improvement Company as industrial power engineer, later engaging in electric rate studies and general supervision of all sales activities.

J. E. Yarmack (A '35, M '43) formerly commercial engineer and aviation application engineer, Federal Telephone and Radio Corporation, New York, N. Y., has been appointed technical representative, International Standard Electric Corporation, New York, N. Y., to foreign commissions in Washington, D. C. Born in Russia in 1900, Mr. Yarmack came to the United States in 1921, was graduated from the Massachusetts Institute of Technology in 1925, studied and taught at Yale University, New Haven, Conn., in 1926, and was naturalized in 1928. Previously he has been associated with the Consolidated Edison Company of New York, Inc., the American Telephone and Telegraph Company, the Square D Company, and the Diehl Manufacturing Company, all of New York. Since 1938 he has been associated with various subsidiaries of the International Telephone and Telegraph Corporation.

S. M. Cooper (A '17) vice-president, United Gas Improvement Company, Philadelphia, Pa., has been elected president of the Delaware Power and Light Company, Wilmington. Mr. Cooper commenced his career in the utility field in 1914 as construction engineer, statistician, and distribution engineer, for the New York and Queens Electric Light and Power Company, Long Island City. Subsequently he was associated with the Counties Gas and Electric Company, Norristown, Pa., before joining the United Gas company as assistant to the electrical engineer. He has been vice-president of the Charleston (S. C.) Consolidated Railway and Lighting Company, the Philadelphia Suburban Counties Gas and Electric Company, and the Philadelphia Electric Company and president of the South Carolina Power Company, Charleston.

Harold Cole (A '19, M '27) formerly distribution engineer, Detroit (Mich.) Edison Company, has been appointed chief planning engineer. Graduating from Cornell University with the degree of mechanical engineer in 1916, he entered the employ of the Detroit Edison Company as assistant distribution engineer, becoming distribution engineer in 1923. **H. W. Collins** (A '22, M '42) formerly assistant to the superintendent of electrical systems has been appointed chief assistant superintendent of electrical systems. Mr. Collins, a graduate of the University of Michigan, had held his former position with the Edison Company since 1919. **G. C. A. Opp** (A '27) formerly safety engineer, recently was appointed safety consultant for the company.

F. E. Brooks (A '38, M '42) formerly assistant vice-president, New York Telephone Company, New York, has been appointed chief engineer of the Long Island area of the company. Mr. Brooks, a graduate of the Case School of Applied Science, has been associated with the New York Telephone Company since 1912, excepting the duration of his service with the Signal Corps of the United States Army during World War I. Commencing his career in the engineering department, Mr. Brooks was made plant extension engineer for the Bronx–Westchester area in 1927 and for the Manhattan area in 1935. He became chief engineer for the Manhattan area in 1939 and assistant vice-president in 1942.

C. A. Cora (A '02, M '34) directory manager, Indiana Bell Telephone Company, Indianapolis, has retired. Born in Buffalo, N. Y., in 1898, Mr. Cora has been connected with the Bell Telephone system since 1899 when he was employed as assistant wire chief

for the American Telephone and Telegraph Company in Buffalo. In 1904 he joined the Central Union Telephone Company, Indianapolis, as division wire chief, becoming division service inspector in 1907, general sublicense agent in 1908, and special agent in 1912. From 1915 to 1920 he was division commercial engineer. In 1920 he was appointed general commercial engineer for the Indiana Bell company and in 1937 was named directory engineer.

C. E. Plummer (A '33, M '37) formerly chief electrical engineer, Modesto (Calif.) Irrigation District, has been appointed chief engineer of the district. Born in Victoria, B. C., in 1901, Mr. Plummer commenced his career as radioman and electrician with the United States Coast Guard from 1921 to 1923. He was employed by the Turlock (Calif.) Irrigation District as electrician in 1923, becoming electrical and service foreman later that year and superintendent of distribution in 1929. In 1936 he joined the Modesto District as chief electrical engineer.

L. P. Joubert (M '35, F '41) formerly chief of the power-plant section of the engineering division of the district office of the United States Engineer, Denison, Tex., has been appointed head of the engineering division of the office. Mr. Joubert has been with the United States Engineers since 1934 when he worked on the Bonneville Project as associate engineer. More recently he has been senior engineer at the Bonneville (Oreg.) district office (1939–41), and at the Portland (Oreg.) district office during 1941.

W. A. Lewis (A '27, M '39) formerly director of the school of electrical engineering, Cornell University, Ithaca, N. Y., has resigned from that position to return to the field of engineering research. He has been named consulting electrical engineer to the Armour Research Foundation at the Illinois Institute of Technology, Chicago, and also research professor in the electrical-engineering department. (For a fuller biography of Doctor Lewis see *Electrical Engineering*, October 1943, page 461.)

L. R. Ludwig (A '28, M '41) division manager, switchgear department Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been named manager of the motor division of that company. Mr. Ludwig has been with the Westinghouse company since 1925 when he graduated from the University of Illinois. As the recipient of the first Lamme Memorial Scholarship, he studied at the University of Berlin in 1929 and 1930.

H. W. Stiner (A '15, F '43) consulting engineer, Cleveland, Ohio, now is associated with the firm of Peter F. Loftus, Consulting Engineers, Pittsburgh, Pa. Mr. Stiner was connected with the General Electric Company in Schenectady, N. Y., and later in Cleveland, from 1913, when he was graduated from Pennsylvania State College, until 1932. As a consultant since 1932 he has been engaged particularly in the central station and mining industries.

L. F. Adams (A '09, F '42) manager of the standards division, General Electric Company, Schenectady, N. Y., has been appointed head of the company's newly created standards policy committee. **H. W. Robb** (M '36) of the standards department and **P. L. Alger** (A '17, F '30) staff assistant to the vice-president in charge of engineering, also have been named to the committee.

Harvey McPhail (A '19, F '42) formerly assistant chief electrical engineer, United States Bureau of Reclamation, Denver, Colo., has been appointed head of the Bureau's new power utilization branch. A 1914 graduate of the University of Nevada, Mr. McPhail has been in the service of the Bureau since 1919 and has been assistant chief electrical engineer at Denver since 1931.

D. E. Howes (A '23, M '35) professor of electrical engineering, Norwich University, Northfield, Vt., has been granted a leave of absence to accept a position in the radio research laboratory, Harvard University, Cambridge, Mass. A graduate of Worcester Polytechnic Institute, Professor Howes joined the Norwich faculty as assistant professor in 1923.

T. C. McFarland (A '22, M '32) formerly associate professor of electrical engineering, University of California, Berkeley, has been appointed chairman of the electrical engineering department. He has been a member of the university faculty since 1920, when he was made instructor. In 1925 he became assistant professor and, in 1931 associate professor.

E. R. Thomas (A '25, M '30) on leave of absence from the Consolidated Edison Company of New York (N. Y.), Inc., has been promoted from the rank of major to that of lieutenant colonel in the United States Army. He is acting chief of research and development of communication equipment at Army Air Force headquarters, Washington, D. C.

E. H. Snyder (A '27, M '33) formerly assistant to the chief engineer, Public Service Electric and Gas Company, Newark, N. J., has been appointed assistant chief engineer. Mr. Snyder, who graduated from Lehigh University, joined the Public Service Company in 1923 as cadet engineer. He had been assistant to the chief engineer since 1937.

A. R. Wellwood (M '22, F '36) lieutenant colonel, Corps of Engineers, United States Army, recently was awarded the Legion of Merit by the War Department for exceptionally meritorious conduct in the performance of outstanding service as assistant to the commandant, Carolina maneuver area, First Army maneuvers, 1941.

J. A. Darling (A '21) formerly chief system dispatcher, Boston (Mass.) Edison Company, has been appointed assistant superintendent of the company's production department. Mr. Darling has been associated with the Boston Edison Company and its predecessor the Edison Electric Illuminating Company of Boston, since 1902.

C. E. Skinner (A '99, F '12) retired assistant director of engineering, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., is serving as civilian engineer in the executive office of the director of the Fort Monmouth (N. J.) Signal Corps Laboratory. Mr. Skinner was president of the AIEE for 1931–32.

R. E. Forman (A '40) formerly chief design engineer, Pacific Power and Light Company, Portland, Oreg., has been appointed superintendent of construction and maintenance. A graduate of Washington State College, he joined the Pacific Power company in 1915 and has been chief design engineer since 1935.

C. W. Jones (A '30) formerly deputy chief of the materials control branch of the Office of War Utilities' power division, has been named chief of the power division's equipment production branch. Before entering Government service, Mr. Jones was associated with the New England Power Service Company, Boston, Mass.

R. P. Brown (A '10, M '13) chairman of the board, Brown Instrument Company, Philadelphia, Pa., has been appointed deputy director of the War Production Board, Third Region. Since 1942 Mr. Brown has been serving as regional consultant to the Defense Plant Corporation, subsidiary to the Reconstruction Finance Corporation.

C. H. Sanderson (A '07, F '18) retired system planning engineer, Consolidated Edison Company of New York (N. Y.), Inc., has joined the division of war research of Columbia University with headquarters in Pasadena, Calif. A fuller biography of Mr. Sanderson appears in *Electrical Engineering*, June 1943, page 271.

Zay Jeffries (M '36, F '42) technical director, lamp department, General Electrical Company, Cleveland, Ohio, has been awarded the Gold Medal of the American Society for Metals, "in recognition of his outstanding metallurgical knowledge and his great versatility in the application of science to the metal industry."

T. O. Eaton (A '28) assistant manager of power-transformer sales, General Electric Company, Pittsfield, Mass., has been made manager of power transformer sales. Mr. Eaton, formerly switchgear specialist at Philadelphia, Pa., was transferred to Pittsfield early in 1943.

R. E. Poole (A '24, M '34) broadcasting development engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has received the additional appointment of assistant director of commercial products development. He has been a staff member of the laboratories since their inception in 1925.

P. E. Bowen (A '41) formerly assistant engineer, Bell Telephone Company of Pennsylvania, Philadelphia, has been transferred to the equipment and building section, plant engineering division, operation and engineering department, American Telephone and Telegraph Company, New York, N. Y.

J. C. Damon (A '05, M '13) recently retired colonel, United States Army, has joined the staff of the Hartford (Conn.) Electric Light Company where he will engage in research on depreciation. A fuller biography of

Colonel Damon appears in *Electrical Engineering*, October 1943, page 462.

E. F. Pearson (M '20, F '37) assistant to the president, Northwestern Electric Company, Portland, Oreg., has been appointed coordinator for Oregon and Washington in the program for co-operation between military authorities and electric companies in the western states.

Joseph Clark (A '26, M '35) engineer, on leave from the Consolidated Edison Company of New York, Inc., now represents Fischbach and Moore, Inc., electrical engineers and contractors, Fontana, Calif., in the Oakland, Calif., office of the iron and steel division of the Kaiser Company, Inc.

A. C. Streamer (A '10, M '41) vice-president, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been named assistant to the president. Associated with the Westinghouse company since 1907, Mr. Streamer was appointed a vice-president in 1941.

Haraden Pratt (A '15, F '37) vice-president and chief engineer, Mackay Radio and Telegraph Company, and vice-president of the Federal Telephone and Radio Corporation, both in New York, N. Y., has been awarded the medal of honor of the Institute of Radio Engineers.

W. S. Gifford (A '16) president of the American Telephone and Telegraph Company, New York, N. Y., recently was awarded the Vermilye Medal of the Franklin Institute, "in recognition of outstanding contribution in the field of industrial management."

N. L. Lituchy (A '40) formerly design project engineer, ignition engineering department, Allison Engineering Division, General Motors Corporation, Indianapolis, Ind., is now mechanical development engineer, Collins Radio Company, Cedar Rapids, Iowa.

J. F. Rader (M '40) formerly electrical engineer, South Carolina Electric and Gas Company, Columbia, has been appointed general superintendent in charge of operation. He has been associated with the South Carolina company since 1925.

L. G. Colson (A '25) engineer in the outside-plant-construction department, Consolidated Edison Company of New York (N. Y.), Inc., has been granted a wartime leave of absence to join the Division of War Research, Washington, D. C.

W. G. Walker (A '24, M '43) senior engineer, testing section, engineering department, Philadelphia Electric Company, has been appointed a member of the sectional committee on electrical measuring instruments of the American Standards Association.

G. R. Woodman (A '27) engineer in the operating department, Southern California Edison Company Ltd., Los Angeles, has been made acting superintendent of hydro-generation. Mr. Woodman has been employed by the Edison Company since 1923.

G. C. Crossman (A '30, M '42) and **Howard Doughtie** (A '30) formerly assistant engineers in the electrical-engineering department of the Consolidated Edison Company of New York (N. Y.), Inc., are now captains in the United States Army.

E. H. Martindale (A '11, M '13) president and general manager, Martindale Electric Company, Cleveland, Ohio, has been appointed to the consolidated metal-cutting tool industries advisory committee formed by the War Production Board.

F. E. Hanson (M '39) manufacturing engineer, Western Electric Company, Kearny, N. J., has been appointed to the mica-capacitor-conservation industry advisory committee formed by the War Production Board.

S. C. Tallman (A '39) formerly a member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., now in England with the United States Army, has been promoted to captain in the mechanized cavalry.

A. B. Rosenstein (A '41) formerly senior electrical engineer, plant engineering department, Lockheed Aircraft Corporation, Burbank, Calif., is now with the Signal Engineering Products Corporation, Los Angeles, Calif.

W. G. Chandler (A '26) formerly superintendent of transmission, Brooklyn Edison Company, has been transferred to the Consolidated Edison Company of New York (N. Y.) Inc., as assistant superintendent of transmission.

J. H. Herron (M '35, F '41) president of the James H. Herron Company, Cleveland, Ohio, recently received the honorary degree of doctor of engineering from the Case School of Applied Science.

G. A. Kositzky (M '22, F '29) chief engineer, Ohio Bell Telephone Company, Cleveland, recently was honored with the degree of doctor of engineering by the Case School of Applied Science.

C. S. Kleinau (A '34, M '41) major, Signal Corps of the United States Army, has been designated acting chief of the aircraft radio branch of the engineering and technical service of the Office of the Chief Signal Officer.

T. F. Barton (A '12, F '30) commercial vice-president and district manager, General Electric Company, New York, N. Y., has accepted the chairmanship of the electrical division for the Fourth War Loan.

W. R. G. Baker (A '19, M '41) vice-president, General Electric Company, Bridgeport, Conn., has been appointed chairman of the new Radio Technical Planning Board of the Radio Manufacturers Association.

L. W. Bates (A '04, M '38) head of the power plant division, Bureau of Yards and Docks, United States Navy Department, Washington, D. C., has been promoted from the rank of commander to that of captain.

H. L. Logan (A '19, F '43) managing engineer, controlens division, Holophane Company, Inc., New York, N. Y., has been elected chairman of the New York section of the Illuminating Engineering Society.

C. J. Lake (A '39) formerly regulator engineer, induction-voltage-regulator department, General Electric Company, Pittsfield, Mass., has been transferred to the company's electronics division at Schenectady, N Y.

A. G. L. McNaughton (A '11, HM '42) lieutenant general, commander in chief, Canadian Active Service Force, recently was made an honorary member of the American Society of Mechanical Engineers.

E. G. D. Paterson (A '21) formerly outside-plant quality engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed systems quality engineer at the laboratories.

R. W. Gilbert (A '36) formerly chief of the aircraft engineering division, Weston Electrical Instrument Corporation, Newark, N. J., has been made director of the company's Rockaway Valley laboratories.

R. C. Rifenburg (A '18, M '35) formerly division engineer, Consolidated Edison Company of New York (N. Y.), Inc., has become plant engineer for the American Locomotive Company, Schenectady, N. Y.

F. B. Wipperman (A '20) representative for the Railway Industrial Engineering Company, St. Louis, Mo., has been elected executive secretary of the National Industrial Service Association.

F. I. Lawson (A '34, M '38) who has been with the Federal Power Commission, Washington, D. C., since 1925, has entered the employ of the Braden Copper Company, Rancagua, Chile.

R. E. Doherty (A '16, F '39) president of the Carnegie Institute of Technology, Pittsburgh, Pa., has been elected president of the Society for the Promotion of Engineering Education for 1943–44.

G. W. Knauer (A '29) chief engineer and plant manager for the North Dakota area of the Northwestern Bell Telephone Company, Fargo, has been granted a wartime leave of absence.

J. A. Hale (M '26) vice-president of the Utah Power and Light Company, Salt Lake City, has been elected president of the Northwestern Electric Light and Power Association.

P. J. Stone (A '38) formerly assistant engineer, technical-service department, Consolidated Edison Company of New York (N. Y.), Inc., is a second lieutenant in the United States Marine Corps.

E. W. Seeger (A '16, F '36) manager of the development department, Cutler-Hammer, Inc., Milwaukee, Wis., has been elected president of the Engineers' Society of Milwaukee.

C. W. Pickells, Jr. (A '30) formerly assistant engineer, Consolidated Edison Company of New York (N. Y.), Inc., is serving as a lieutenant in the United States Army in the South Pacific.

R. C. Earle (A '27) formerly assistant engineer, Brooklyn (N. Y.) Edison Company has been transferred to the gas-production department of the company's Astoria (N. Y.) plant.

E. C. Byrd (A '34) formerly tester, Consolidated Edison Company of New York (N. Y.), Inc., is now a corporal in the United States Army and is stationed at Hammer Field, Calif.

D. T. Osgood (A '37) formerly member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., has been promoted to major in the United States Army.

A. C. Marshall (A '14, F '29) president and general manager, Detroit (Mich.) Edison Company, has been elected president of the Detroit Industrial Safety Council.

H. L. Miller (A '38) president, Utilities Engineering Company, Philadelphia, Pa., has been elected president of the Electrical Association of Philadelphia for 1944.

G. T. Minasian (A '25, M '30) distribution engineer, Consolidated Edison Company of New York (N. Y.), Inc., has been elected mayor of Glen Ridge, N. J.

C. A. Collier (M '23) vice-president, Georgia Power Company, Atlanta, has been named president of the company's postwar planning committee.

L. F. Motl (A '30) formerly of the 50th Transport Wing, United States Army, Camp Williams, Wis., has been promoted to major and assigned to Pope Field, Fort Bragg, N. C.

Rawson Bennett II (A '38) formerly lieutenant commander, Bureau of Ships, United States Navy, Washington, D. C., has been promoted to the rank of commander.

OBITUARY ••••

Axel Julius Körner (A '16, F '39) consulting engineer, Stockholm, Sweden, died in August 1943. Born April 12, 1880, in Stockholm, he was graduated from the Royal Institute of Technology in 1902. He entered the testing department of the Swedish General Electric Company, Vasteras, Sweden, in 1903 and became chief of the department in 1904. In 1906 he was connected with the General Electric Company, Schenectady, N. Y., and the Allis-Chalmers-Bullock Manufacturing Company, Montreal, Que. Returning to the General Electric Company in Sweden in 1907 he engaged in experimental work on railway motors and equipment. From 1911 to 1914 he directed the company's work on the first large single-phase electrification in Sweden and in 1915 was made chief engineer of the railway department. After a period, 1916 to 1919, as a consulting engineer, he was appointed chief engineer for the Luth and Rosén Electric Company and remained in that position from 1920 to 1923. Since 1924 he had practiced as a consulting engineer on electric power and railway electrification. Mr. Körner was also editor of the electrical section of the *Teknisk Tidskrift* since 1918 and instructor in electrotechnics at the Royal Institute of Stockholm since 1931. He served as chief consulting engineer for the city of Stockholm on urban and suburban traffic problems and as member of the Swedish National Committee of the International Electrotechnical Commission and as president of the subcommittee on electric traction. He was president of the Swedish Institute of Electrical Engineers for 1921–22; vice-president of the Swedish Society of Consulting Engineers in 1932; and member of the board of Elektrotechnischer Verein, Berlin, Germay, 1933–35. He served his Government as member and secretary of the committees on railway electrification and on inductive interference from 1920–23; as secretary of the committee on electric-power taxes in 1930; and as special member of the royal court of taxation in 1936. He was the author of technical books and papers and holder of several patents.

Howard Burton Shaw (A '97) professor and head of the industrial engineering department, North Carolina State College, Raleigh, died December 15, 1943. Professor Shaw, who was born in Winslow, Me., August 5, 1869, received from the University of North Carolina the degrees of bachelor of arts in 1890, and bachelor of commercial science in 1891; and from Harvard University the degree of master of arts in 1894. He was instructor in mathematics at the University of North Carolina from 1889 to 1890 and instructor in surveying and drawing from 1891 to 1893. He was assistant in the electrical-engineering laboratory at the Lawrence Scientific School of Harvard University from 1894 to 1896. He joined the faculty of the University of Missouri in 1896 as assistant professor of electrical engineering and was named professor in 1899. He was appointed dean of the school of engineering in 1907 and director of the engineering experiment station in 1909. He served as commissioner on the Missouri Public Service Commission from 1913 to 1917 and afterwards as educational director of the Doherty Training Schools until 1922. He was first associated with the North Carolina State College as director of the engineering experiment station in 1923, and became professor of industrial engineering in 1932 and head of the department in 1941. He was a member of Phi Beta Kappa, Sigma Xi, Eta Kappa Nu, the Society for the Promotion of Engineering Education, and the Society for the Advancement of Management.

Murray Charles Beebe (A '98, F '13) in charge of the research department, Lea Manufacturing Company, Waterbury, Conn., died November 28, 1943. Mr. Beebe who was born February 25, 1876 and received the degree of bachelor of science in electrical engineering from the University of Wisconsin in 1897. He remained at the University of Wisconsin, Madison, as instructor in electrical engineering until 1900. After an interval as research engineer for George Westinghouse and the Nernst Lamp Company, Pittsburgh, Pa., he returned to the University of Wisconsin as head of the department of electrical engineering in 1907 and retained that position until 1918. During World War I he worked on submarine detectors and signaling devices at the Western Electric Company, New York, N. Y. He joined the Wadsworth Watch Case Company, Dayton, Ky., in 1920 as chief engineer, and the Scovill Manufacturing Company, Waterbury, in 1925 as director of its research laboratories. In 1942 he took charge of the research department of the Lea Company. Mr. Beebe served on the AIEE board of examiners for 1942–43. He was a member of the American Chemical Society and honorary member of the staff of the University of Connecticut. Several patents have been issued in his name. He was a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

Brian Chandler Bellows (M '36) toll facilities director, Bell Telephone Laboratories, Inc., New York, N. Y., died December 22, 1943. Born June 10, 1884, in Mandan, N. Dak., Mr. Bellows received the degree of mechanical engineer from Cornell University in 1906. Entering the employ of the American Telephone and Telegraph Company, New York, N. Y., he studied service and force requirements for the long-lines traffic department and in 1909 was made toll line engineer. In that capacity he was employed by the Western Union Telegraph Company, New York, N. Y., in 1912 and became traffic engineer in 1914. Returning to the American Telephone company in 1914 as service engineer, he was appointed division traffic superintendent in 1920. In 1923 he was transferred to the Illinois Bell Telephone Company, Chicago, as general supervisor of toll traffic only to return to the American Telephone Company in 1926 as toll switching facilities engineer. His connection with Bell Laboratories dated from 1934 where he became first toll facilities engineer and since 1935 director of toll facilities.

Harold Elijah White (A '03) design engineer, Wilkinsburg, Pa., died November 29, 1943. Mr. White was born December 11, 1875, in Camillus, N. Y., and was graduated from Cornell University with the degree of mechanical engineer in 1898. He commenced his career as design engineer in the railway engineering department for the General Electric Company, Schenectady, N. Y., in 1899. In 1913 he entered the employ of the Crocker-Wheeler Company, Ampere, N. J., as controller engineer, remaining in that position until 1922 when he took a position in the control engineering department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. His work for the Westinghouse company mostly pertained to marine auxiliary controllers. Since 1932, he had been unemployed except for a short term of employment with the Works Progress Administration. More than 25 patents had been issued in his name. He was a member of the American Institute of Mechanical Engineers.

W. Ward McKinley (A '38, M '42) chief engineer, plant 5, the Sparks-Withington Company, Jackson, Mich., died November 10, 1943. Mr. McKinley, who was born in Harrisburg, Ohio July 24, 1908, was graduated from Ohio University in 1927 with the degree of electrical engineer. He was employed by the Rochester and Pittsburgh Coal and Iron Company, Indiana, Pa., as cost analyst and steam-plant engineer from 1927 to 1929, in which year he joined the Youngstown (Ohio) Sheet and Tube Company as electrical draftsman and designer. From 1931 to 1937 he was electrical engineer for the public water-supply system for Mahoning Valley sanitary district, Youngstown. With the Commonwealth and Southern Corporation from 1937 to 1942, he supervised electrical design, particularly on automatic switching and remote indicating and metering apparatus. In 1942 he entered the employ of the Sparks-Withington Company as production engineer and chief draftsman.

Charles E. Eckels (A '30) electronic engineer, Minneapolis-Honeywell Regulator Company, Cleburne, Tex., died November 16, 1943, in a plane accident. He was born January 11, 1908, in Ben Avon, Pa., and was graduated from Carnegie Institute of Technology in 1928 with the degree of bachelor of science. He was employed as assistant in the laboratory of inductive coordination school, American Telephone and Telegraph Company, New York, N. Y., in 1928, and in 1929 was made instructor in the company's school for new technical employees in Pittsburgh, Pa., where he was employed until 1933. In 1935 he became district representative for A. M. Byers Company, Pittsburgh, Pa., and in 1940 was transferred to Lakewood, Ohio, as company representative. In 1943 he entered the employ of the Minneapolis-Honeywell company, Minneapolis, Minn., and later was transferred to Texas.

George Guy Warwick (A '27, M '35) superintendent, Ruskin (B. C.) power plant, Western Power Company of Canada, died recently. He was born November 15, 1880, in Surrey, England. He commenced his career as an apprentice marine engineer for Powell and Thompson, Tonbridge, Kent, England, in 1896. He also was connected with the Eadie Manufacturing Company, Birmingham, England, and the Birmingham Small Army, Ltd., before leaving England in 1913 to enter the employ of the Vancouver Power Company at Lake Buntzen, B. C. From 1915 to 1918 he served in the British army and from 1918 to 1920 worked for the British Columbia Electric Railway Company, Vancouver. Returning to the Vancouver Power Company in 1920 he worked as master mechanic until 1926 when he was made superintendent at Lake Buntzen. In 1937 he was appointed superintendent of the Ruskin Power Plant.

Joseph E. Hood (A '38) department of water and power, City of Los Angeles, Calif., died recently. Mr. Hood was born July 29, 1889, in Butte, Mont., and after holding various apprentice mechanical and electrical positions in California and Arizona became master mechanic for the Goodrich Lockhart Development Company, Jerome, Ariz. His association with the Los Angeles department of water and power dated from 1918 when he took charge of field maintenance and repair of electrical and hydraulic power-plant and station machinery. In 1923 he was given the official title of electrical foreman. Since 1935 he also had been responsible for the electrical repair section, the general plant division, and, after 1936, the frequency change section. Supervision of the maintenance, repair, and necessary redesign of the electrical machinery at the first four 82,500-kva units at Boulder power plant was also among his duties.

Allan Percy Bender (A '18) assistant application manager, transformer division, Westinghouse Electric and Manufacturing Company, Sharon, Pa., died October 22, 1943. Born in Pittsburgh, Pa., July 18, 1886, he was graduated from the University of Pittsburgh in 1906 with the degree of electrical engineer. Joining the Westinghouse company in 1906 as an engineering apprentice, he was made transformer design engineer in 1907, and commercial engineer in 1911. In 1918 he served as a member of the War Industries Board, Washington, D. C. Appointed manager of the sales section for power transformers in 1919, he became transformer sales manager in 1935. In 1942 he was named assistant application manager. Mr. Bender was chairman of the AIEE Sharon Section for 1932–33 and a member of the National Electrical Manufacturers Association.

Daniel Frederic Potter, Jr. (M '31) manager of the New York, N. Y., office of the Kuhlman Electric Company, died November 5, 1943. Born September 15, 1893, in Buffalo, N. Y., Mr. Potter received the degree of mechanical engineer from Cornell University in 1916. After several months in the test course of the General Electric Company at Lynn and Pittsfield, Mass., he joined the Robertson-Cataract Electric Company, Buffalo, as sales engineer. In 1923 he became a partner in the firm of Hoffman and Potter which represented the Sundh Electric Company, Newark, N. J.; the Howell (Mich.) Electric Motor Company; the Peerless Electric Company, Warren, Ohio; and the Kuhlman Electric Company, Bay City, Mich. When this partnership was dissolved in 1924, he organized the New York office of the Kuhlman company.

John Vincent Hilford (A '35) assistant inspector, Philadelphia (Pa.) Signal Corps Procurement District, died September 18, 1943. Mr. Hilford was born December 16, 1910, in Caney, Kans., and was graduated from the University of Kansas with the degree of bachelor of science in electrical engineering in 1934. He was employed by the Kansas State Highway Commission in 1935 and entered the employ of the Phoenix Engineering Corporation, Wichita, Kans., in 1937. After periods of employment with the Kansas Gas and Electric Company, Wichita, and the Sedgwich County Engineers' Office, Wichita, in 1940, he entered the employ of the Government as civil engineer in Kansas City, Mo., in 1941 and was transferred to the Signal Corps of the United States Army later that year.

Maurice Herman Paleschuck (A '43) tutor in electrical engineering, College of the City of New York, N. Y., died December 28, 1943. He was born May 13, 1916, in New York City and was graduated from the College of the City of New York in 1942 with the degree of bachelor of electrical engineering. From 1935 to 1940 he was employed as an instructor to testers and trouble shooters by Emerson Radio and Television, Inc., New York, N. Y. In 1941 he became a laboratory assistant for the department of electrical engineering at the College of the City of New York and in 1942 was appointed tutor in electrical engineering. He was an associate member of the Institute of Radio Engineers.

Frank J. Reynolds (A '20) retired engineer, Hartford (Conn.) Electric Light Company, died December 19, 1943, in Rockymount, N. C. Born May 24, 1867, in Clermont, N. H., he was graduated from Dartmouth College in 1889. From 1889 to 1917 he was employed by the Thomson-Houston Electric Company and its successor, the General Electric Company. In 1890 he was made assistant district engineer for the company at Cincinnati, Ohio, and in 1898 general construction foreman in Schenectady, N. Y. In 1907 he was transferred to the New York (N. Y.) district where he had charge of the installation of large apparatus. In 1917 he joined the Hartford Electric Light Company as chief engineer.

MEMBERSHIP

Recommended for Transfer

The board of examiners at its meeting on January 20, 1944, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Dewars, A. G., mgr., system planning, Northern States Power Co., Minneapolis, Minn.
Hoover, P. L., prof. of elec. engg., head of dept., Case School of Applied Science, Cleveland, Ohio.
Penman, R. F., chief reactor engineer, Ebasco Services, Inc., New York, N. Y.
Sisson, C. E., managing engr., Canadian General Electric Co., Toronto, Ont., Canada.

4 to grade of Fellow

To Grade of Member

Allen, H. J., vice-president, Garrett Engg. Co., Houston Tex.
Beatty, Fred, associate professor of elec. engg., Colorado State College, Fort Collins, Colo.
Berger, F. J., senior engr., Philadelphia Electric Co., Philadelphia, Pa.
Billau, L. S., elec. engr., Baltimore & Ohio Railroad, Baltimore, Md.
Black, F. S., assistant system planning engr., Potomac Electric Power Co., Washington, D. C.
Bowman, J. C., engr., Public Service Elec. & Gas Co., Newark, N. J.
Churchill, T. C. D., foreign wire relations engr., Bell Telephone Co., Toronto, Ont., Canada.
Coffman, E. S., principal rate investigator, Federal Power Commission, Washington, D. C.
Eames, W. F., consulting engr., Westinghouse Electric Elevator Co., Jersey City, N. J.
Fellowes, H. S., transformer dept. supt. State Electricity Comm. of Victoria, Melbourne, Australia.
Gillespie, J. F., supt., Elec. pwr. and maintenance, Holston Ordnance Works, Tennessee Eastman Corp., Kingsport, Tenn.
Henderson, J. W., elec. engr., Washington Suburban Sanitary Comm., Hyattsville, Md.
Henschke, W. O., asst. research engr., American Bosch Corp., Springfield, Mass.
Lincks, G. F., head of design section, General Elec. Co., Pittsfield, Mass.
Logan, F. G., mgr. of development, Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Lovoff, Adolph, elec. engr., Navy Dept., Bureau of Ships, Washington, D. C.
MacDonald, Wm. R., Major, Office of the Chief Signal Officer, Washington, D. C.
McAvoy, F. E., associate research and div. engr., and director of Target Div., General Bronze Corp., Long Island City, N. Y.
McCammon, F. F., vice-president in charge of elec. operations, Public Service Co. of Colorado, Denver, Colo.
Neubauer, E. O., transmission engr., Illinois Bell Telephone Co., Chicago, Ill.
Peck, H. B., post engr., Woodrow Wilson General Hospital, Staunton, Va.
Ramsay, H. B., senior electric distribution engr., New Orleans Public Service, Inc., New Orleans, La.
Reardon, J. W., designer, D.C. motors and generators, General Electric Co., Fort Wayne, Ind.
Rushmore, L. A., asst. supervising distribution engr., Long Island Lighting Co., Roslyn, N. Y.
Saldana, A. E., president and mgr., Cia. de Alumbrado Electrico de San Salvador, El Salvador, Central America.
Smith, F. D., elec. engr., Consolidated Steel Corp., Ltd., Orange, Tex.
Snively, H. D., motor and generator engg. div., General Electric Co., Schenectady, N. Y.
Taugher, F. F., New England District Engg. & Service Mgr., Westinghouse Elec. & Mfg. Co., Boston, Mass.
Wall, J. V., elec. engr., Vern E. Alden, Chicago, Ill.
Warner, C. W., engr., Cutler-Hammer, Inc., Milwaukee, Wis.

30 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. Any member objecting to the election of any of these candidates should so inform the national secretary before February 29, 1944, or April 30, 1944, if the applicant resides outside of the United States or Canada.

To Grade of Member

Adler, W. M. (Re-election), Fischbach & Moore, Inc., Alexandria, Va.
Bailey, F. W., Capt., U. S. Army, Columbus, Ohio.
Berumen, J. A. (Re-election), Calle de Blanco, Torreon, Coah., Mex.
Bobe, S. A., Westinghouse Elec. and Mfg. Co., Atlanta, Ga.
Bogdanowicz, W. A. (Re-election), Clinton Engineer Works, Oak Ridge, Tenn.
Brodhead, W., Weston Electrical Instrument Corp., Boston, Mass.
Burris, A. P., Electric Machinery Mfg. Co., Minneapolis, Minn.
Colby, C., Utilities Section, S.C.A.D., A.P.O. 726, c/o Postmaster, Seattle, Wash.
Croll, H. A., Ill. Bell Tel. Co., Chicago, Ill.
Ingalls, R. D. (Re-election), Diehl Mfg. Co., Somerville, N. J.
Holmdahl, N. G., U. S. Bureau of Reclamation, Coulee Dam, Wash.
Howk, C. L. (Re-election), Federal Tel. & Radio Corp., East Newark, N. J.
Karplus, E., General Radio Co., Cambridge, Mass.
Larsh, E. P., The Master Electric Co., Dayton, Ohio.
Leidigh, W. A., Jr. (Re-election), Portland Gen. Elec. Co., Portland, Oreg.
Little, D. G., Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Maxon, R. D. (Re-election), Public Service Co. of Ill., Chicago, Ill.
McIlvaine, D. K., Alco Valve Co., St. Louis, Mo.
Olschner, E. W., Carolina Tel. & Tel. Co., Tarboro, N. C.
Peterman, L. C. (Re-election), Ford, Bacon & Davis, Inc., New York, N. Y.
St. Clair, H. (Re-election), Tennessee Valley Authority, Chattanooga, Tenn.
Short, G. W., United States Rubber Co., Bristol, R. I.
Thompson, P. W., Detroit Edison Co., Detroit, Mich.
Tietze, H. W. (Re-election), Public Service Elec. & Gas Co., Newark, N. J.
Weaver, B. S. (Re-election), General Electric Co., Schenectady, N. Y.
Wentzel, A. G., Jr., Aluminum Co. of America, Burlington, N. C.
Whiting, F. T., Westinghouse Elec. & Mfg. Co., Chicago, Ill.

27 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Aubuchon, M. A., General Elec. Co., Schenectady, N. Y.
Bower, R. V., Allis-Chalmers Mfg. Co., Boston, Mass.
Brueckner, L. J., Bell Aircraft Corp., Buffalo, N. Y.
Burton, Lester W., General Electric Co., Bridgeport, Conn.
Cameron, D. H., Major, U. S. Army, Bradley Beach, N. J.
Erickson, C. H., General Elec. Co., Buffalo, N. Y.
Felten, R. G., Yale Univ., New Haven, Conn.
Gibson, H., General Elec. Co., Schenectady, N. Y.
Hasensler, F. B., General Elec. Co., Boston, Mass.
Hoffman, H. F., Bristol Co., Waterbury, Conn.
Hsu, F. T., General Elec. Co., Schenectady, N. Y.
Larock, F. N., So. New England Tel. Co., New Haven, Conn.
Macredis, G., Westinghouse Elec. Elevator Co., Jersey City, N. J.
McKinney, C. R., General Elec. Co., Schenectady, N. Y.
Pinkham, T. A., Jr., Boston Edison Co., Boston, Mass.
Shaver, O. B., Int. Bus. Mach. Corp., Endicott, N. Y.
Shumaa, J. W., General Elec. Co., Lynn, Mass.
Straight, A. L., Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
Thomas, H. W., New York State Electric & Gas Corp., Binghamton, N. Y.
VanKirk, S. D., New York State Elec. & Gas Co., Elmira, N. Y.
Wagner, J. L., International Bus. Mach. Corp., Endicott, N. Y.
Williams, J. R., General Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Abele, W. B., The Ohio Power Co., Philo, Ohio.
Acock, G. W. (Re-election), J. A. Roebling's Sons, Trenton, N. J.
Bancroft, W. H., Jr., Ed. G. Budd Mfg. Co., Philadelphia, Pa.
Barden, V. A., Major, U. S. Army, Dayton, Ohio.
Benedict, F. T., U. S. Army Signal Corps, Audubon, N. J.
Berghoefer, F. G., Naval Research Lab., Washington, D. C.
Brannen, P. M., Union Switch & Signal Company, Swissvale, Pa.
Conway, C. B., Consolidated Gas Elec. Light & Pr. Co., Baltimore, Md.
Danielson, G. E., Sr., Goodyear Aircraft Corp., Akron, Ohio.
Davis, R. E., Naval Research Lab., Washington, D. C.
Dennis, C. E., Chesapeake & Potomac Tel. Co., Washington, D. C.
Driver, J. P., Radio Corp. of America, Lancaster, Pa.
Emani, J. R., Bureau of Ships, Washington, D. C.
Falke, J. A. (Re-election), General Elec. Co., Cincinnati, Ohio.
Flath, E. H., Jr., Univ. of Cincinnati, Cincinnati, Ohio.
Flynn, J. V. (Re-elcrtion), Master Electric Co., Dayton, Ohio.
Halsted, R. L., Allis-Chalmers Mfg. Co., Charleston, W. Va.
Jenkins, R. W. (Re-election), Cons. Gas Elec. Light & Pr. Co. of Baltimore, Baltimore, Md.
Joline, E. R., Philadelphia Electric Co., Philadelphia, Pa.
Kirkpatrick, E. L., U. S. Navy, Washington, D. C.
Langell, S. A., Zanesville, Ohio.
Locke, J. F., U. S. War Dept., Dayton, Ohio.
Mitchell, C. A., Day & Zimmermann, Inc., Philadelphia, Pa.
Moss, B. W., Western Elec. Co., Inc., Baltimore, Md.
Osborne, C. H., Electric Storage Battery Co., Pittsburgh, Pa.
Payne, H., Wright Field, Dayton, Ohio.
Reed, A. L., West Virginia Univ., Morgantown, W. Va.
Schantz, G. W., Master Electric Co., Dayton, Ohio.
Schweinfurth, D. F., Tel. & Tel. Services, Portsmouth, Ohio.
Shields, A. B., Victoreen Instrument Co., Cleveland, Ohio.
Smith, S. L., Philadelphia Trans. Co., Philadelphia, Pa.
Stafford, K. E., Cleveland Elec. Ill. Co., Cleveland, Ohio.
Wallin, C. I., Westinghouse Elec. & Mfg. Co., Cleveland, Ohio.
Wehmann, G. W., Sylvania Elec. Prod., Inc., Emporium, Pa.
Young, E. L. (Re-election), General Motors Corp., Dayton, Ohio.

3. New York City

Beirne, W. J., Airborne Instrument Labs., Mineola, N. Y.
Bomer, P. A., Federal Tel. & Radio Corp., East Newark, N. J.
Burns, L., Jr., Lieut., U. S. Army, New York, N. Y.
Cohen, C. L., Federal Radio & Tel. Corp., East Newark, N. J.
Fritschy, V. P., Westinghouse Elec. Elev. Co., Jersey City, N. J.
Gurevich, D., Freed-Transformer Co., New York, N. Y.
Heath, E. H., Jr., Westinghouse Elec. Elev. Co., Jersey City, N. J.
Hickson, K., Long Island Lighting Co., Roslyn, N. Y.
Hune, F. L., Jr., Jersey Central Pr. and Lt. Co., Asbury Park, N. J.
Kolmorgen, E. L., Anaconda Wire & Cable Co., Hastings on Hudson, N. Y.
Marmeller, J. M., New York Tel. Co., Brooklyn, N. Y.
Perry, W. P., Curtiss-Wright Corp., Caldwell, N. J.
Pollaeck, E. H., Federal Tel. & Radio Corp., East Newark, N. J.
Rhein, G. W., Mackay Radio & Tel. Co., New York, N. Y.
Rich, E. M., 222 E. 35th St., New York, N. Y.
Unfricht, A. J., W. S. Rockwell Co., New York, N. Y.
Walker, E. C., Curtiss-Wright Corp., Caldwell, N. J.
Wells, S. E., War Research Div., Columbia Univ., Mineola, N. Y.
White, K. E., Electrical Testing Labs., New York, N. Y.

4. Southern

Allison, R. W., Robert & Co. Inc., Atlanta, Ga.
Brower, W. E., Memphis Light, Gas & Water Div., Memphis, Tenn.
Burton, W. A., West Virginia Pulp & Paper Co., Covington, Va.
Elder, G. E., Sr. (Re-election), Dept. of Public Utilities, Radford, Va.
Morgan, P. N., Tenn. Valley Auth., Chattanooga, Tenn.
Roach, J. E., Alum. Co. of America, Alcoa, Tenn.
Shirley, R. C., Tenn., Eastman Corp., Oak Ridge, Tenn.
Shoemaker, F. B., Tenn. Valley Auth., Chattanooga, Tenn.
Stewart, F. G., Jr., Alum. Co. of America, Alcoa, Tenn.
Wiggins, C. Q., Jr., Alum. Co. of America, Alcoa, Tenn.
Wright, I. R., Alum. Co. of America, Alcoa, Tenn.

5. Great Lakes

Cronau, G. G., Cutler-Hammer, Inc., Milwaukee, Wis.
Dodge, W. A., Jr., U. S. Army, Fargo, N. Dak.
Durand, S. R., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Fairly, A. S., Commonwealth & Southern Corp., Jackson, Mich.
Jerome, B. A., Bemis Bros. Bag Co., Peoria, Ill.
Krug, J. P., Detroit Edison Co., Detroit, Mich.
Markee, M. S., Delco Star Electric Co., Chicago, Ill.
Miller, N. E., Allis-Chalmers Mfg. Co., West Allis, Wis.
Montgomery, W. O., Pub. Serv. Co. of Ind., Indianapolis, Ind.
Morris, J. P., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Ragsdale, W. H., General Motors Corp., Flint, Mich.
Robinson, R. R., Board of Public Works, Niles, Mich.
Schroeder, J. M., Univ. of Minn., Minneapolis, Minn.
Sorensen, R. A., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Stroh, W. J., Zenith Radio Corp., Chicago, Ill.
Swayne, J. B., Illinois Pr. Co., Bloomington, Ill.
Wilkins, H. F., Lafayette, Ill.
Williams, S. B., Globe-Union, Inc., Milwaukee, Wis.
Williams, V., Westinghouse Elec. and Mfg. Co., South Bend, Ind.
Wimmer, E. V., Kyle Corp., South Milwaukee, Wis.
Wright, T. D., Square D Co., Detroit, Mich.

6. North Central

Grant, O. M., American Tel. & Tel. Co., Denver, Colo.
Morgan, H. A., Westinghouse Elec. & Mfg. Co., Denver, Colo.
Ramsey, J. D., Remington Arms, Inc., Denver, Colo.
Williams, W. T., Bur. of Reclamation, Kremmling, Colo.

7. South West

Blackman, H. W., Pennsylvania Shipyards, Beaumont, Texas.
Boose, H. C., Univ. of Okla., Norman, Okla.
Byrd, E. C., Winston Bros. Co., Port Neches, Texas.
Chamberlain, P. S., Westinghouse Elec. & Mfg. Co., El Paso, Texas.
Council, J. B., Westinghouse Elec. & Mfg. Co., Houston, Texas.
Dear, J. F., Pennsylvania Shipyards, Inc., Beaumont, Texas.
Erhart, F. J., Southwestern Bell Tel. Co., St. Louis, Mo.
Gust, M. J., J. Gordon Turnbull & Sverdrup & Parcel, St. Louis, Mo.
Harder, D. C., Oklahoma Gas & Elec. Co., Oklahoma City, Okla.
Hussers, J. A., Southwestern Bell Tel. Co., St. Louis, Mo.
Kendall, F. P., American Smelt. & Ref. Co., Vanadium, N. M.
Mangrum, G. R., Southwestern Bell Tel. Co., St. Louis, Mo.
Metzdorf, E. K., AT&SF Ry. Co., Topeka, Kans.
Parmele, E. G., Electric Service Supplies, Inc., Dallas, Texas.
Peery, C. A., Texas Co., Dallas, Texas.
Rall, F. A., Southwestern Bell Tel. Co., St. Louis, Mo.
Rather, D. I., Houston Pipe Line Co., Houston, Texas.
Rey, W. A., Oklahoma Gas & Elec. Co., Oklahoma City, Okla.
Shaw, R. W., Aluminum Co. of America, Malvern, Ark.
van der Meulen, J. F. W., Tin Processing Corp., Texas City, Texas.
Zavada, A. J., Square D Co., Houston, Texas.

8. Pacific

Adamson, R. T., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Dwyer, F. J., Board of Education, San Francisco, Calif.
Hegardt, K. E., Southern Calif. Tel. Co., Los Angeles, Calif.
Lipscomb, W. L., Cons. Vultee Aircraft Corp., San Diego, Calif.
Male, A. N. (Re-election), Southern Calif. Tel. Co., Los Angeles, Calif.
McKee, R. W., Southern Calif. Tel. Co., Los Angeles, Calif.
Miller, W. A., Southern Calif. Tel. Co., Los Angeles, Calif.
Minvielle, L., U. S. Navy, San Francisco, Calif.
Peairs, M. H., Douglas Aircraft Co. Inc., Santa Monica, Calif.
Shackman, D. E., Southern Calif. Tel. Co., Los Angeles, Calif.
Sproul, J. E., Southern Calif. Tel. Co., Los Angeles, Calif.
Wallace, S. J., Western Pipe & Steel Co., South San Francisco, Calif.

9. North West

Carlson, E. L., Puget Sound Power & Light Co., Seattle, Wash.
Hamilton, R. F., Northwestern Elec. Co., Portland, Oreg.
Hughes, H. R., E. I. duPont de Nemours & Co., Pasco, Wash.
Johnson, C. L., Winslow Marine Rwy. & Shipyard, Winslow, Wash.
Kinyon, A. L., Bonneville Power Admin., Portland, Oreg.
Scarborough, W. E., Bonneville Power Admin., Portland, Oreg.
Schrengohst, J. H., Puget Sound Power & Light Co., Dieringer, Wash.
Worth, R. A., Northwestern Electric Co., Portland, Oreg.

10. Canada

Buckley, E. F., Univ. of Toronto, Toronto, Ont., Can.
Gareau, E. A., McGill Univ., Montreal, Que., Can.
Mason, C. T., Redfern Construction Co. Ltd., West Toronto, Ont., Can.
Millican, G. W., Montreal Light Heat & Power Cons., Montreal, Que., Can.
Thomson, A. G., Canadian Gen. Elec. Co., Ltd., Peterboro, Ont., Can.

Elsewhere

Arguelles, C. R., Elec. Engr., Mexico, D. F., Mex.
de Jesus, P. M., Rio de Janeiro Tram., Lt. & Pr. Co., Ltd., Rio de Janeiro, Brazil, S. A.
Desdier, F., CIA Industrial de Guadalajara Ateinajac, Jal., Mex.
Fernandez, A., Neuva Cia. Electrica Chapala, S. A., Guadalajara Jal., Mex.
Fernandez Varela, C., Westinghouse Elec. Int. Co., Monterrey, N. L., Mex.
Garduno Fernandez, J., Comunicaciones y Obras Publicas (SCOP), Mexico, D. F., Mex.
Jasso, C. G., Nua Cos. El. Chapal, S. A., Quadalajara, Jal., Mex.
Meaney, A., Gen. Elec. Co., Guadalajara, Jal., Mex.
Pena, P. G., Elec. Engr., Herramientas, Mexico, D. F., Mex.
Quirarte, L., CIA Ind. Nel. S. A., Guadalajara, Jal., Mex.
Tavera, E. G., Institute Cordiologio, Mexico, D. F., Mex.

Total to grade of Associate
United States and Canada 159
Elsewhere 11

OF CURRENT INTEREST

New Committee to Study Power Needs of Liberated Areas

A Public Utilities Committee has been organized to "assemble all pertinent facts and recommend such action as may be advisable concerning requirements, supplies, and production of equipment to re-establish electric, gas, and water services in liberated and former enemy areas which may be required during the relief period," according to recent announcement by the Combined Production and Resources Board.

The United Nations Relief and Rehabilitation Administration will refer requirements of liberated areas to the Combined Board for consideration in relation to other military or civilian claims for the same supplies. The Combined Board will make recommendations on how far the requirements put forward by UNRRA can be met and from what source; the Public Utilities Committee will assist the Combined Board to perform this task in its particular field.

The chairman of the committee and American member will be J. A. Krug, director of the Office of War Utilities, War Production Board. The member for Great Britain will be Sir Henry Self, deputy United Kingdom member of CPRB; the member for Canada will be T. H. Hogg, chairman of the Hydro-Electric Power Commission of Ontario.

The Committee is expected to survey requirements and the availability of utility equipment and to decide, in conjunction with other operating organizations of the three governments, on any necessary production programs for equipment to meet basic utility needs in liberated and former enemy areas.

INDUSTRY

5,000-Kw Power Plant Installed in Eight Railroad Cars

A 5,000-kw central station has been designed which may be completely assembled on a railway train of eight cars. It is adapted for using coal of unusually low quality and operating in arid regions and in temperature ranges from 110 degrees above to 40 degrees below zero Fahrenheit. The power plant, a product of Westinghouse Electric and Manufacturing Company, can be set up to deliver power in 48 hours' time, it is reported.

The first two cars carry the air-cooled condensers, while third car carries the turbine generator with switchgear equipment. The fourth and fifth cars take care of auxiliary equipment and water storage. The water storage supply will run the train, under most severe conditions, for more than a full day without replenishment. The sixth and seventh cars are for the boilers while the eighth provides quarters for the crew and storage for lubricating oils, spare parts, and so forth.

The two boilers produce steam at 600 pounds gauge, 750 degrees Fahrenheit from available coals—even lignite, having a heat content of only 7,000 Btu per pound, will work satisfactorily. Boilers are of water-tube double-drum construction and have both forced and induced draft fans and air-operated locomotive-type stokers. The single turbine-generator unit delivers to the bus 6,250 kva at 80 per cent power factor, 6,300 volts. Power is delivered to a six-cubicle, metal-clad switchgear for distribution. Because intake ventilating air may be dusty or dirty, the generator is provided with a self-cleaning air filter. A Diesel-driven generator provides 75 kw capacity for plant and auxiliary purposes.

Four motor-driven propeller fans draw air over eight coolers in each of the condenser cars. Even with cooling air at 95 degrees Fahrenheit the condensers are able to condense the full amount of steam; the condenser water is then pumped back to the feed-water tank car. By this method it is expected that less than three per cent make-up water will be required. All make-up water is filtered, softened, and evaporated in the auxiliary car.

Placing a modern 5,000-kw plant into a train of eight cars presented scores of engineering problems. The trucks were designed to be specially rigid so that no torsional movement of the frame in transit can rupture pipe connections. All apparatus—meters, shafts, gauges, and so forth—are braced so as not to be injured by a sudden stop of the train. Pipe and electric circuits between cars are disconnected while the train is en route. Because of the tight fit in the turbine-generator car, the sides are removable to give access to the generating unit should dismantling be necessary. Therefore, supports for a crane, overhead piping, and conduit are all built up independently from the floor.

TVA Releases Annual Report

A net income of $13,148,000 was returned to the United States Treasury from gross revenues of $31,670,000 accruing from the sale of electric power by the Tennessee Valley Authority during the fiscal year ending June 30, 1943, according to the report submitted by that body to the President on January 1, 1944. TVA also reported the receipt of gross revenues of $34,670,000 and a combined net income of $5,806,000 by the 128 municipal and co-operative distribution systems which are wholesale customers of TVA, serving 523,000 ultimate consumers.

Most of the other varied activities TVA reported for the year were connected with the war effort. Of the 9,000,000,000 kilowatt-hours of electric energy generated, three quarters were used by war industries. Production of 77,300 tons of concentrated phosphatic fertilizers for food production in Great Britain and the United States and development of equipment and techniques for preserving food were reported. Large quantities of ammonia, ammonium nitrate, and elemental phosphorus for munitions and calcium carbide for synthetic rubber were produced; 24,000 square miles of strategic areas were mapped for the War Department; electric generating plants were designed for the Soviet Government; Army medical officers were trained in methods of malaria control; training in resource-development administration was provided for engineers from South American countries and from China; and new mobile housing construction methods for use in war projects were developed.

Copies of the report may be obtained from the Superintendent of Documents, Washington, D. C.

New Turbine Blade Evolved

A new impulse turbine blade suitable for use on large 3,600-rpm units which it is said will pass a life test of 1,000 hours with no indication of weakening has been evolved as a result of a four-year research program. The turbine blade, now in use at Westinghouse Electric and Manufacturing Company, is smaller than the old one—$1^1/_2$ inches wide instead of 2. The root by which it is fastened to the turbine rotor is shaped like an inverted U. Three of these blades are brazed together, forming one solid segment. Each three-blade segment is fastened to the rotor by two crosswise pins.

During the four-year program several types of blades were tested on a special test turbine, with a wide variety of temperatures, loads, and speeds. About 120,000 photographic records were taken of the turbine in operation.

Segment of new impulse turbine unit

Lighting Handbook Issued by Westinghouse Lamp Division

A Lighting Handbook, designed as a practical guide and working reference book for lighting engineers, designers, architects, and builders and originally scheduled for release after the war, has been issued by the lamp division of Westinghouse Electric and Manufacturing Company.

A feature of the handbook is a series of charts which co-ordinate room index, fixture efficiency, and coefficient of utilization curves and provide a new and graphic method of determining the desired illumination for various applications. Charts cover industrial and commercial fluorescent and incandescent lighting and provide a means of calculating quickly the number and size of lamps needed with practically every type of lighting fixture.

The book is divided into two parts, chapter headings in the first section including: Lighting Terms and Measurements, Recommended Levels of Illumination, Interior Lighting Design Calculations, Interior Wiring for Lighting. In the second half of the book, devoted to specific lighting applications, there are chapters covering store, office, school, public buildings, industrial, architectural, aviation, and street and highway lighting.

A limited number of copies is available at one dollar each.

147,000-Kw Turbogenerator Installed in Chicago Station

A new 147,000-kw turbogenerator, reputed to be the largest steam generating unit to be built in the United States since the beginning of the war, has been placed in service at the Fisk station of the Commonwealth Edison Company in Chicago. This generator which feeds energy into the power pool embracing the territories served by Commonwealth Edison Company, Public Service Company of Northern Illinois, Western United Gas and Electric Company, and Illinois Northern Utilities Company, brings the aggregate system net capacity to 2,254,000 kw. A peak system load of 1,928,000 kw was registered on December 15, 1943.

Operating at a speed of 1,800 rpm and at a steam pressure of 1,300 pounds per square inch, the new unit is driven by two pulverized-coal-fired boilers with a combined capacity of 100 tons of coal per hour and capable of delivering 1,500,000 pounds of steam per hour. The Allis-Chalmers Manufacturing Company constructed the turbogenerator and Babcock and Wilcox Company the boilers.

Tiny Fluorescent Lamp Designed. A new fluorescent lamp consuming one tenth of a watt, suitable for marker purposes where low illumination with low energy consumption is desirable, has been announced by Westinghouse Electric and Manufacturing Company. The lamp contains two spiral electrodes in a gaseous atmosphere. A discharge takes place when about 100 volts alternating current or 140 volts direct current is applied across the electrodes. A tiny resistor in the lamp base stabilizes current flow after discharge begins.

American Edition of Engineers' Digest Issued

An American edition of *The Engineers' Digest*, an English technical journal reporting on progress in engineering research and development abroad, was introduced into the United States in December 1943. Created to enable a large number of readers to keep in touch with the significant engineering articles selected, digested, and translated from magazines published overseas, the new edition will continue to be published monthly in this country.

Copies of the digest, or an annual subscription, can be obtained by writing to E. D. Publications, Inc., 1 Madison Ave., New York 10, N. Y. Two of the 30 abbreviated articles appearing in the first issue are on electrical subjects.

The prototype of the American *Engineers' Digest* was established in England in 1940. It was designed to circumvent the language handicap, and to isolate for the attention of busy engineers with limited reading time the noteworthy articles from the world's engineering literature. It functions through a committee of what may be termed specialist engineers, formed for consultative purposes to sift the journals of other countries for desirable papers, and to supervise their condensation and translation.

OTHER SOCIETIES •

Fatalities in Electric Utilities Analyzed in NSC Report

Analysis of the circumstances and causes of fatal accidents in electric utilities, based on the details of 193 fatal and 29 other severe accidents reported by members of the public-utilities section of the National Safety Council, has been made in the Council's Accident Facts Memo *U-1* "Deaths and Serious Injuries Resulting From Electric Shock and Burns in the Electric Utility Industry."

Electric shock and burns resulted in by far the highest proportion of the fatalities—70 per cent, or 136 cases. Fatal falls from poles, ladders, trees, and towers ranked next, accounting for 13 per cent, or 24, of the deaths. Accidents caused by motor vehicles were third.

The unsafe acts of employees were factors in 95 per cent of the accidents. Lack of safeguards, particularly the use of rubber gloves, line hose, and rubber blankets, was a factor in 50 per cent of the instances. Failure to use protective equipment was usually the result of disobedience of instructions by the injured person and was the outstanding personal cause.

The majority of fatal accidents occurred in handling wires and tools in removing or installing lines and transformers; splicing and connecting wires and other apparatus; and inspecting and repairing, re-fusing, and checking switches, transformers, and similar equipment. Another outstanding factor was work done on hot lines which could have been degenerized. Since electrocutions are responsible for such a large percentage of the fatal injuries, elimination of the principal causes of such accidents offers the biggest opportunity for reducing deaths in the industry.

Future Meetings of Other Societies

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 20–24, 1944, New York, N. Y.

American Society for Testing Materials. Spring meeting, March 1–2, 1944, Cincinnati, Ohio; 47th annual meeting, June 26–30, 1944, New York, N. Y.

American Society of Mechanical Engineers. Spring meeting, April 3–5, 1944, Birmingham, Ala. Semi-annual meeting, June 19–20, 1944, Pittsburgh, Pa.

Engineering Institute of Canada. Annual meeting, February 1–11, 1944, Quebec, Que.

National Electrical Manufacturers' Association. April 23–7, 1944, Chicago, Ill.

National Fire Protection Association. May 8–11, 1944, Philadelphia, Pa.

RMA Names Eight New Committees for War and Postwar Work

Eight new committees of Radio Manufacturers Association, for immediate work on many problems of the war program and for future plans and conferences with government agencies on postwar industrial problems, have been appointed by R. C. Cosgrove of the Crosley Corporation, Cincinnati, Ohio; chairman of the RMA set division and of the postwar planning committee.

The committees and their chairmen are:

Industry reconversion—A. S. Wells of Wells-Gardner and Company, Chicago, Ill.; former president of RMA.

Employment and personnel—A. H. Gardner of Colonial Radio Corporation, Buffalo, N. Y.

Sales financing—J. P. Rogers of Farnsworth Television and Radio Corporation, Fort Wayne, Ind.

Industry statistics—Ross D. Siragusa of the Admiral Corporation, Chicago, Ill.

Advertising—John S. Garceau of the Farnsworth Television and Radio Corporation, Fort Wayne, Ind.

Distribution costs—Ben Abrams of Emerson Radio and Phonograph Corporation, New York, N. Y.

Export program—W. A. Coogan of the RMA export committee.

Contract terminations—chairman not yet announced.

The committee on postwar planning will co-ordinate the work and consider detailed recommendations of the various groups.

International Illumination Conference Report Available

The essential substance of the proceedings of the last prewar International Illumination Conference held in Holland in June 1939 has been made available by the United States National Committee of the International Commission on Illumination in a condensed all-English version, with table of contents and index. Copies may be obtained at five dollars each (less than the cost of publication) from Arthur A. Brainerd, executive secretary of the Committee, Philadelphia (Pa.) Electric Company, 900 Samson St.

The proceedings of the ten-day Holland conference, which in former years have been reproduced in three languages, originally were to have been printed in Austria. However, German invasion at the outbreak of the

war prevented this, as it later prevented the Holland National Committee, which acted as host during the meeting, from assuming responsibility for publication. The United States National Committee then undertook the preservation of an unofficial report.

Electron Microscope Society Holds First Meeting

A comprehensive review of the effect of the electron microscope on the development of scientific research and production control was provided by the program of the first official meeting of the Electron Microscope Society of America, an associate society of the American Institute of Physics, in New York, N. Y., January 14 and 15, 1944.

In particular the Stanford University and the General Electric microscopes were discussed. Papers on lenses and specimen preparation, on the microscope's application in the fields of bio'ogy and metals and alloys, and its use in determining molecular weights were presented.

The officers of the new society are: R. B. Barnes, American Cyanamid Company, Stamford, Conn., *president;* A. F. Prebus, Ohio State University, Columbus, *vice-president;* M. C. Banca, Magnolia, N. J., *secretary-treasurer;* and V. K. Zworykin (M '22), Princeton, N. J., O. S. Duffendack, University of Michigan, Ann Arbor, *directors.*

IPCEA Specifications for Cable Revised. Interim revisions of the Insulated Power Cable Engineers Association Specifications for Varnished Cambric Insulated Cables, Fourth Edition, July 1939, to be effective during the war emergency period, have been announced. These revisions which have also been adopted by National Electrical Manufacturers Association cover Section 8.2, Cloth and Varnish Coating; Section 13.1, Class of Braid; Table IX, Thickness of Braid; Section 14.1, Tape; Section 21.3, Insulation Resistance Correction Factors; Table XV; Tables XVI and XVII, Minimum Insulation Resistance.

JOINT ACTIVITIES

ASA Approves War Standard for Glass Radio Insulators

The American Standards Association has announced the approval of a new American War Standard for Glass Radio Insulators (C75.8-1943), developed by a group of representatives of the radio industry in conjunction with representatives from the Signal Corps and the Bureau of Ships. The project was undertaken at the request of the War Production Board to aid in the preparation of new manufacturing facilities for glass insulators, and it is expected to facilitate production of these units as well as to simplify their procurement for the Armed Forces.

The specifications cover performance requirements, test methods, and standard dimensions for a standard series of glass insulators of the quality required by the Army and Navy. The detailed information is illustrated by a number of diagrams, and the appendix of the Standard is comprised of design criteria considered in good practice. The basic specification for glass material is the American War Standard on Ceramic Insulating Materials, class *L* (C75.1-1943).

Copies of the new Standard may be obtained at 50 cents per copy from the ASA, 29 West 39th St., New York 18, N. Y. Also it may be obtained without charge, for procurement purposes only, from the government agency concerned.

ASA Publishes New List of Standards

The American Standards Association announces the publication of its new list of standards, covering specifications for materials, methods of tests, dimensions, definitions of technical terms, procedures, and the like. More than 600 standards are listed, 64 of which have been approved or revised since publication of the last price list in April 1943. Among others, the new list includes 95 safety standards.

Since the war, the ASA has been working very closely with the Government agencies and with the Armed Forces to provide specifications for certain of the materials necessary to the war effort. Because these standards are developed through an accelerated procedure, they are designated as American War Standards and are listed separately. Already there are 40 of these completed and many more are under development. Every Government order is based on specifications, and these standards are used to accelerate production, conserve materials, maintain a balance between quality and price control, and to simplify inspection, contracting, and subcontracting.

The complete list of American Standards will be sent free of charge to anyone interested. Requests should be addressed to the American Standards Association, 29 West 39th St., New York 18, N. Y.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

"Faith of the Engineer"

To the Editor:

During the Christmas respite I have been pondering "The Faith of the Engineer," as approved by Engineers' Council for Professional Development, and published in the December 1943 issue of *Electrical Engineering.* Though not a religious creed, it bears a close relationship to it, since true religion must express itself in the whole of life, of which one's profession or means of livelihood constitutes so large a part.

If the EPCD statement is examined from this point of view, the dominant note is the Christian ethic. The ideals of honesty, integrity, and service to humanity are exalted as the things which will give our profession dignity and in which we may take a humble pride. Rightly so.

Then there is a paragraph beginning, "Since the Age of Stone, human progress has been conditioned by the genius of my professional forebears." Is this the Christian conception of human progress? In these days surely we must recognize that human progress is more truly measured by spiritual qualities than by the multitude of material comforts and conveniences, and our greatest need is the spirit of brotherhood whereby the world may be made safe for scientific advances and their applications. The sentence quoted sounds rather materialistic and perhaps even arrogant.

While the distinctive contribution of engineers to society is of a material nature, engineers as a class are not blind to the fact that a basically spiritual problem is not solved by physical and material means. I believe that engineers are not behind others in recognition of the supreme value of the spiritual forces that make for righteousness and for peace on earth, good will among men. Should not "The Faith of the Engineer" remind us of the pre-eminence of these spiritual values?

C. KENT DUFF (M '41)
(Meter engineer, Hydro-Electric Power Commission of Ontario, Toronto)

NEW BOOKS . . .

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

American Patent System. By W. B. Bennett. Louisiana State University Press, Baton Rouge, La., 1943. 259 pages, illustrated, 9 by 5½ inches, cloth, $3. (ESL.)

Written from an economic viewpoint, this book describes our patent system and discusses its uses and abuses. Many questions involving the patentee, the corporate concern, and the public are answered explicitly, with reference to court decisions and the opinions of research workers and businessmen. The book is intended to be of use to students, inventors, corporations, and interested laymen.

Mac's (MacQuown's) Directory of Coal Operating Companies. Eighth edition. National Coal Publications, Berger Building, Fourth Avenue and Grant Street, Pittsburgh, Pa., 1943. 204 pages, 12 by 9 inches, stiff paper, $7.50. (ESL.)

This directory lists the coal operating companies of America by states and by names of companies and of mines. The names of officials and purchasing agents and information as to equipment, number of employees, daily output, and yearly output for the years 1938–41 inclusive are given.

Planning 1943. American Society of Planning Officials, 1313 East 60th Street, Chicago, Ill. 1943. 175 pages, charts, etc., 9½ by 6 inches, cloth, $2. (ESL.)

The proceedings of the 1943 meeting of the American Society of Planning Officials and the papers presented at the meeting are included in this volume. Among the topics discussed are the effect of the war upon our cities, regional councils in metropolitan areas, national planning, urban redevelopment and the planning problems of cities.

Alternating-Current Circuits. By R. M. Kerchner and G. F. Corcoran. Second edition. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, London, England, 1943. 553 pages, illustrations, etc., 8½ by 5½ inches, cloth, $4.75. (ESL.)

This is a textbook intended for junior students who have had the usual courses in calculus. The new edition has been revised thoroughly and rearranged somewhat, and many illustrative examples and problems added.

Fundamentals of Radio. By L. O. Gorder, K. A. Hathaway, and C. H. Dunlap. American Technical Society, Chicago, Ill., 1943. 373 pages, illustrated, 8½ by 5½ inches, cloth, $2. (ESL.)

This textbook is intended for a first-level course following the War Department's recommended outline. It covers general electrical and radio theory, the principles and use of basic radio equipment, acoustics and acoustical apparatus, and the construction of transmitters and receivers. A glossary of terms is included.

Piping Stress Calculations Simplified. By S. W. Spielvogel. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 83 pages, illustrated, 11½ by 8½ inches, cloth, $2.50. (ESL.)

This volume provides exact solutions to numerous typical problems in the calculation of pipe stress under changing temperatures. Arithmetical solutions are presented and the mathematical theory involved is discussed. The book is intended to assist the designer of piping layouts.

Patent Law. By C. H. Biesterfeld. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1943. 225 pages, 8½ by 5½ inches, cloth, $2.75.

The basic principles of our patent law are presented and illustrated by citation of and quotation from court decisions. The book is intended for persons without legal training who, in their daily work, are confronted at times with questions of patent law and practice.

Symposium on Paint. American Society for Testing Materials, Philadelphia, Pa., 1943. 60 pages, illustrated, 9 by 6 inches, paper, $1; to members, 75 cents. (ESL.)

This booklet contains seven papers presented at the Buffalo spring meeting of the ASTM in 1943. The papers deal with developments in drying oils and fatty acids; with surface coating of opaque pigments and calcium carbonate extenders; and with emulsion paints, paints for protective concealment, black-out paints, and luminous paints.

Radiographic Inspection of Metals. By O. Zmeskal. Harper and Brothers, New York, N. Y., and London, England, 1943. 150 pages, illustrated, 7¾ by 5 inches, cloth, $2.75. (ESL.)

This introductory manual gives a clear practical account of methods of radiographic inspection of metals. The equipment used, the fundamentals of radiographic practice, and the applications are discussed.

Mechanical Loading of Coal Underground. By I. A. Given. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 397 pages, illustrated, 9½ by 6 inches, cloth, $4. (ESL.)

Theory and practice are both covered in this manual. Many mining plans for all types of equipment and all seam conditions are given. The varieties of equipment are described. Face preparation power supply, and the maintenance of equipment also are discussed.

House of Goodyear. By H. Allen. Goodyear Aircraft Corporation, Akron, Ohio, 1943. 417 pages, illustrated, 9½ by 6 inches, cloth, $2. (ESL.)

This history traces the development of The Goodyear Tire and Rubber Company from its organization in 1898 down to the present day. In addition to being the story of a great enterprise, it is an important contribution to the history of rubber, the development of modern business, and the relations of capital and labor.

Clear the Tracks! By J. Bromley. McGraw-Hill Book Company (Whittlesey House Division), 1943. 288 pages, woodcuts, 8½ by 5½ inches, cloth, $2.75. (ESL.)

This autobiographical work is a humorous and nostalgic story of the "good old days" when railroading was a personalized affair. Along with the personal narrative of the author's experiences runs a background of detail showing the growth of the railroads from the early wood-burning locomotive days to the present.

Aircraft Electrical Engineering. By R. Matson. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 372 pages, illustrated, 9 by 6 inches, cloth, $3.50. (ESL.)

This text is intended for courses in aircraft electrical engineering which prepare the student as directly as possible for such work in the engineering departments of aircraft factories. An acquaintance with electrical theory is assumed, and the theory of design is omitted. Emphasis is on the practical problems that confront the engineer.

ASTM Methods of Chemical Analysis of Metals 1943. American Society for Testing Materials, Philadelphia, Pa., 323 pages, illustrated, 9½ by 6 inches, cloth, $2.50; paper, $2. (ESL.)

This volume contains adopted and tentative standards for apparatus and reagents, for sampling, and for the analysis of commercial metals and alloys. The methods are intended for use in the buying and selling of materials according to specifications.

Steam Turbine Operation. By W. J. Kearton. Fourth edition. Pitman Publishing Corporation, New York, N. Y.; Sir Isaac Pitman and Sons, Ltd., London, England, 1943. 375 pages, illustrated 9, by 5½ inches, cloth, $5. (ESL.)

The popularity of this practical text on the installation, running, maintenance, and testing of steam turbines, is shown by the publication of four editions in 12 years. In addition to instructions, the author has included descriptive matter which will enable the engineer to understand the construction of the plant and which explains the thermal and mechanical considerations that affect its operation. The chapters on glands and governing have been rewritten for this edition, and a chapter on thrust bearings has been added.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Building Codes—An Essential Tool in Urban Development. Chamber of Commerce of the United States, Washington, D. C., 15 pages.

The Rubber Industry and the War. The Rubber Manufacturers Association, Inc., 444 Madison Avenue, New York, N. Y., 80 pages.

They're Turbosupercharged. General Electric Company, Publicity Divisions, Schenectady, N. Y., 32 pages, no charge.

Research in Steatite Porcelains. By J. O. Semmelman, J. W. Lennon, and A. S. Watts. The Ohio State University, Columbus, 47 pages, 50 cents.

Production for Victory, 1943. National Association of Manufacturers, 14 West 49th Street, New York 20, N. Y., 64 pages, 25 cents.

The Tocco Process. By H. B. Osborn, Jr., The Ohio Crankshaft Company, Cleveland 1, 32 pages.

What Management Can Really Do to Reduce Absenteeism. 28 pages. **Representative Cost Systems in the Plastics Industry.** 16 pages. **Preventing and Correcting Low Power Factor.** 8 pages. **Scientific Selection of Office Personnel Increases Production.** 4 pages. George S. May Business Foundation, 111 South Dearborn Street, Chicago 3, Ill., no charge.

Fires in the Second Year of War. National Fire Protection Association, 60 Batterymarch Street, Boston 10, Mass., 23 pages, 25 cents.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Design Features of Generators for Diesel-Electric Switcher Locomotives

C. A. ATWELL
MEMBER AIEE

Synopsis: Simplicity and reliability have been kept foremost in generators recently developed for Diesel-electric switcher locomotives ranging from ten to 80 tons. New motors and control equipment have been developed at the same time. This paper deals especially with the generators, their electrical and mechanical features, and performance characteristics, both as power generators and as motors for engine starting from the locomotive battery. Operating fundamentally as self-excited generators, separate exciters have been eliminated. The simplicity of the generator windings has allowed corresponding simplicity of control circuits.

THE Diesel-electric-locomotive generator is part of a portable power plant. This power plant is built into the locomotive, and, if it does not function correctly, the locomotive does not do its work properly. This power plant must be reliable and controlled easily under variable conditions of weather, location, motion, and frequently varying load.

Mechanical and electrical simplicity and durability are very desirable features if one wishes to obtain continued and reliable service with operators that are not always acquainted thoroughly with electrical equipment. Simplicity of the control scheme is also dependent mainly on the generator performance characteristics and windings.

The purpose of this paper is to explain the electrical and mechanical features of some of the recent generators that have been developed for industrial switcher locomotives and railway switchers up to approximately 80 tons.

Paper 44-25, recommended by the AIEE committee on land transportation for presentation at the AIEE winter technical meeting, New York, N. Y., January 24-28, 1944. Manuscript submitted November 13, 1943; made available for printing November 30, 1943.

C. A. ATWELL is design engineer in the transportation engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Mechanical Requirements

Generators with a single bearing at the commutator end have been adopted as standard for the sake of mechanical design simplicity. The armature is supported at the engine end by the engine crankshaft. This arrangement uses the smallest number of parts and provides for the closest coupling between the generator and engine.

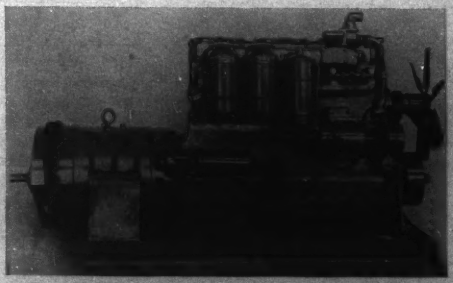


Figure 1. Engine–generator unit arranged for three-point support

1,800 rpm, 140-horsepower net input

Steel-disk couplings, flexible to angular misalignment, are employed on the higher-speed engine–generator combinations, where the generator stator is bolted solidly to an engine bell housing. The coupling flexibility takes care of slight inaccuracies in machining that may prevent the engine shaft and the generator shaft from being exactly in line. The steel-disk coupling does not have rotational flexibility. This is not desirable as the generator armature should act as a flywheel for the engine, thus allowing the engine flywheel to be cut down in weight merely to what is necessary for coupling purposes. When the generator stator is rigidly connected to the engine by being bolted to a bell housing, the whole power plant is mounted with a three-point support (see Figure 1). Two of these support points are at the sides of the generator frame, and the third point is at the opposite end of the engine. This three-point support makes it easy to provide a flexible mounting for the complete power plant when resilient supports at these three mounting points are supplied.

Another common method of combining the engine and generator into a unit power plant is that of supporting both on a rigid bedplate (see Figure 3). Means are provided for aligning the generator shaft accurately with the engine crankshaft before the generator frame feet are bolted solidly to the bedplate and doweled in position.

The first impression that the layman gets, in looking at the engine–generator set for a Diesel-electric locomotive, is that the generator is much smaller than the engine. This, however, is not something for the generator designer to boast about. It is due to the inherent fact that the really active material of the engine requires a lot of attachments and

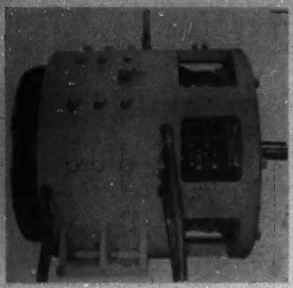


Figure 2. A generator used on 25- to 50-ton locomotives

1,000 rpm, 170-horsepower net input

auxiliaries for its proper functioning, whereas the electric generator is nearly all active material of either electric or magnetic circuits.

How large should a generator be to operate with a given engine? One engineer expressed it by saying that the generator should be able to do anything that the engine will do. This is a rough but simple way of stating it and is a very general guide. The Diesel engine and the d-c electric generator are such different types of power machines, however, that there is more to it than such a simple statement. More specifically, the generator size is determined usually by the torque and speed that the engine can supply to it continuously and by the maximum volts and maximum amperes demanded of the generator by the electric driving motors in order to meet the required locomotive performance. The most economical generator size is obtained when both it and the driving motors are designed at the same time, with proper regard to voltage and ampere values.

Naturally, generators directly connected to high-speed engines are smaller than those for slow-speed engines. Usually, engines with operating speeds below 1,500 rpm are called slow-speed, and those above 1,500, high-speed, for locomotive service.

Generators designed for this service are usually all new, so that there is a freedom of choice of the ratio of diameter to length. The result is always a compromise between the short and fat and the long and skinny types. This compromise is the result of consideration of the economical ratio of diameter to length of the armature core, the diameter that will best suit mounting with the given engine and a minimum over-all length of the engine–generator set. Another factor affecting this ratio is the critical speed of the rotating members of the engine and generator taken together. In some cases the diameter of the generator armature has been made smaller than it would have been, for the other reasons just mentioned, in order to reduce the armature WR^2 and keep away from critical speed vibrations that might cause dangerous stresses in the rotating parts.

This type of generator is well suited to effective self-ventilation by a fan on the armature shaft. The generator is nearly always mounted in a protected compartment, so that it is not necessary to enclose the space around the commutator other than to provide a cover over the top to protect the commutator and brush holders from falling objects. The arrangement shown in Figure 3 is especially effective in providing clean air for cooling the generator and using the air exhausted from it to assist in ventilating the engine compartment. A vertical partition in the enclosing hood (not shown in Figure 3) is located at the center of the generator body and prevents hot air from the engine compartment being used to ventilate the generator. In this case, the blower for force-ventilating the traction motors and control, the air compressor, and the auxiliary generator are arranged conveniently to be driven from a shaft extension at the commutator end without in any way preventing easy access to the brush holders and commutator.

Electrically, the generator must act as a generator for supplying power to the motors and also as a battery-driven motor for cranking the engine. These two types of electrical performance will be considered under separate headings.

Performance Characteristics as a Generator

When the performance curves of a Diesel-electric locomotive generator are discussed, we must always keep in mind the fact that it is supplied with a rather definitely limited amount of power input. Unlike the ordinary powerhouse lighting generator, the voltage cannot be kept constant over a wide range of ampere load. This is due to the fact that an increase in amperes, without a corresponding decrease in voltage, means an increase in power beyond the ability of the engine. The ideal generator-regulation characteristic is one that supplies just the right voltage at any ampere load and speed, so that its output plus the losses will balance exactly the power supplied to the generator. In other words, the problem of the generator regulation is to make its power input balance the output of the engine at any ampere load demanded by the traction motors and at any speed and throttle opening of the engine.

Many types of separate exciters and field-current regulators have been considered for properly adjusting the generator field strength at different ampere loads, so that just the right voltage is obtained. Many of these schemes are too complicated or introduce factors of unreliability or additional cost or maintenance to have found favor for use on small- and medium-size switcher locomotives.

The type of generator that gives a close approximation of the ideal regulation, and at the same time an ultimate in simplicity, is a modification of the ordinary self-excited d-c generator. The modifications consist of adding a small percentage of separate excitation from the locomotive battery and a special unsymmetrical shaping of the main pole faces. The unsymmetrical main-pole shaping is allowed, because the rotation is always in the same direction. The object of this pole-face shaping is to change the load saturation curves with respect to the

Figure 3. A locomotive power-unit arrangement that affords easy access and good ventilation for both generator and engine

1,000 rpm, 295-horsepower net input

Figure 4. 65-ton Diesel-electric railway locomotive

Figure 5. Ten-ton Diesel-electric industrial switcher locomotive

no-load saturation curve, so that the field excitation provided by the self-excited and battery fields will approach closely that required for the ideal voltage regulation. This effect results from a compounding action that counteracts the effect of armature reaction to the desired degree.

Figure 6 shows test voltage and speed regulations of a generator driven by a Diesel engine delivering 275 net horsepower to the generator at 1,200 rpm. From F to E on the speed curve, or C to B on the voltage curve, the generator is absorbing full-throttle power from the engine. Over this part of the curve the engine speed is determined by the load the generator demands from it. Since the speed is approximately constant, the horsepower input is also approximately constant.

At E the engine governor starts to operate, and the speed from E to D is determined by the governor and not the generator load. The part of the voltage curve BA is the voltage that the generator will produce at this governed speed with the same field setting as for the full-throttle operation from C to B. Point B is called the "unloading point." Most of the operation of a switcher locomotive will be over the voltage range from C to B, and, when maximum power and speed are required over this range, the operator will use wide-open throttle. Actually, in switching service, or even in so-called "transfer service," full throttle is not used for a very long period of time. At partial-throttle positions, both speed and voltage are lower at any given amperes. Since amperes represent locomotive tractive effort, partial throttle and lower voltage simply mean lower speed at a given tractive effort.

In cases where the locomotive is required to do high-speed service at light tractive efforts, it is desirable to provide a second field setting so that a higher-voltage unloading point will be obtained, as at J. This is obtained by decreasing the amount of resistance in the self-excited field circuit when the voltage has increased to G. This change is conveniently made with a voltage relay. This permits full-throttle loading with speed H_1–K and voltage G_1–J. At K the engine governor begins to operate, and at lower ampere loads the speed is determined by the governor, and the generator produces voltage J–L.

It is obvious that, if full power were taken from the engine at very low amperes, the voltage required would be very high. The minimum amperes for which the unloading point is set must be chosen with due respect to the maximum voltage that the generator commutator is good for and the voltage required by the traction motors to provide the specified high-speed performance of the locomotive.

It should be kept in mind that the performance shown in Figure 6 is the maximum performance of the power plant, and that most of the operation will be at less power and correspondingly lower speed and volts. This lower power performance will be a result of the operator not using full throttle. Diesel engines for locomotive service are not intended for full-throttle operation continuously. The generator could operate continuously between two limits of continuous rating. The upper limit of continuous ampere rating is determined by the heating of the main current-carrying parts, such as armature windings, commutating field windings, and commutator; the minimum limit, by heating of the self-excited field which has increased amperes and resulting increased heating as voltage rises.

The battery field uses only a few amperes from the battery and is left on at all loads. The purpose of this separately excited battery field is to provide a positive flux in the magnetic circuit and definite voltages at the lower operating speeds. The special shaping of the main pole faces is of assistance to the battery field in this respect.

Performance Characteristics as a Starting Motor

The most convenient method of engine cranking is to use the generator as a starting motor. This eliminates the necessity for a separate starting motor, its mounting and gearing to the engine flywheel.

A series motor characteristic is necessary to provide both high breakaway torque and the required firing speed and torque. A separate series main-field winding is built into the generator especially for this purpose. At starting, this field winding is connected in series with the armature and commutating field. This starting-motor circuit is connected directly to the battery terminals until the engine fires.

Engine builders are usually in a position to furnish information on the breakaway torque required to start the engine

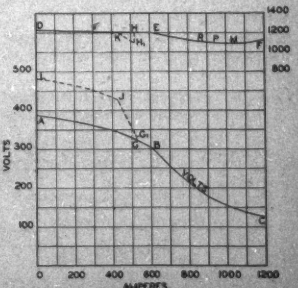


Figure 6. Typical generator-voltage and speed-regulation curves

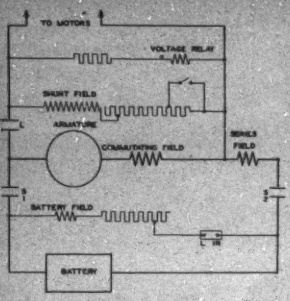


Figure 7. Schematic control diagram showing simplicity of circuits

from zero speed and the speed and torque, required at firing. The best method of obtaining this information, with all mechanically driven auxiliaries connected as in service, is by means of an oscillographic test recording volts, amperes, and speed of the generator acting as a starting motor. The values of speed, torque, current, and volts during starting are such rapid transients that ordinary meter readings are very uncertain.

Figure 8 is a tracing of a typical oscillogram of such an engine-starting test. A 60-cycle timing wave was included in addition to the values of volts, speed, and amperes. In this case speed was recorded by a disk mounted on the engine shaft that made eight contacts per revolution. The speed at any point along the curve can be obtained by finding the number of cycles of the timing wave corresponding to a certain number of the speed-indicating impulses. For example, at the firing point, four speed indications or one-half revolution correspond to 8.4 divisions on the 60-cycle timing wave, or 214 rpm.

In this oscillogram the current record is used to measure instantaneous torque. The actual torque is obtained by referring to an ampere–torque curve, previously obtained from factory test of the generator as a series motor. The initial inrush of current is not a measure of breakaway torque, since this current is limited only by the impedance of the circuit and would represent more torque than is required to start the engine turning. The ripples in the current curve indicate variations of torque due to the cylinder compressions. The maximum value of the first full compression has been taken as the current corresponding to maximum breakaway torque. This value, scaled from the oscillograph, is 355 amperes. From the ampere–torque curve for the generator used in this test, this current corresponds to a torque of 1,040 pound-feet.

After breakaway, acceleration continued up to a time of approximately 2.0 seconds, after which the speed was nearly constant, as indicated by the equal spacing of the speed-indicator impulses.

When the engine fired, a sudden decrease in current took place. The point is accurately determined when a tangent is drawn to the tops of the ripples of the current curve just ahead of this decrease. The engine firing in this case started at 3.18 seconds after 9.15 revolutions, at a speed of 214 rpm at 315 pound-feet torque. A number of such tests should be taken under varied conditions of temperature, engine-oil viscosity, and length of time the engine has been standing. This information is necessary to provide data for designing the series-field winding of a new generator and to determine the characteristics of the battery that will be required to insure engine starting under these conditions.

Table I

Commutating-Field Winding	Volts	Amperes
In	27.5	375
Out	34.5	325

Figure 9 is a typical curve of a generator operating as a series starting motor obtained from factory test under steady-state conditions. The curve is plotted as shown so that either breakaway or firing torque can be read from it and also the voltages required. The torque curve was determined when pounds were read at the end of an arm clamped to the shaft under locked condition. This was checked when torque was calculated from inputs, speeds, and losses while it ran at 30 volts. Theoretically, the torque, when running, should be slightly less than the locked torque, but the speed is low and the field strength comparatively low in comparison with the operating conditions as a generator, so that the rotational losses are practically negligible. The running and locked torques are, therefore, plotted as one curve for simplification.

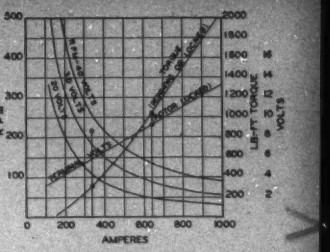


Figure 9. Typical curve of generator operating as a series starting motor

To illustrate the use of this curve, let us use the values of torques and speed obtained from the oscillograph test and determine what values of volt and amperes this generator will require to start the engine. (Incidentally, the oscillograph test was taken on a different type of generator prior to the development of this one.) The breakaway torque of 1,040 will require 640 amperes and 9.2 terminal volts. The firing torque of 315 at 214 rpm will require 335 amperes and a terminal voltage of 35. The latter value is obtained by interpolating between the 30- and 40-volt speed curves.

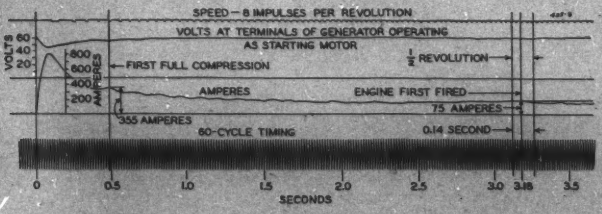


Figure 8. Typical oscillogram of test to determine engine-starting requirements

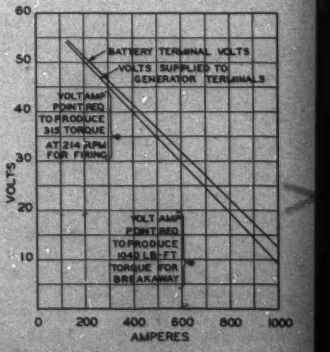

BATTERY TERMINAL VOLTS
VOLTS SUPPLIED TO GENERATOR TERMINALS
VOLT-AMP POINT REQ TO PRODUCE 315 TORQUE AT 214 RPM FOR FIRING
VOLT AMP POINT REQ TO PRODUCE 1040 LB-FT TORQUE FOR BREAKAWAY
VOLTS
AMPERES

Figure 10. Battery volt-ampere curve with volt-ampere points for a given engine's starting requirements

Figure 10 shows these volt-ampere points located on the same plot with the voltage of a proposed battery. The battery-voltage curves were obtained from the battery manufacturer's data. Such data are usually given in volts per cell and amperes per positive plate. It is plotted here as total amperes and terminal volts for the battery considered. The volts drop from battery to generator terminals must be accounted for. This drop includes that of such switches and contactors as are in the starting circuit. It is advisable to utilize liberal cable size in this circuit and to keep the lengths as short as possible, because a few volts drop multiplied by the amperes required represent a large percentage of the power being drawn from the battery.

If the volt-ampere points for breakaway and firing lie well below the generator-terminal voltage curve, then the battery proposed can be considered as adequate.

The question is sometimes asked as to why the commutating-field winding is not omitted when the generator is used as a starting motor at the comparatively low battery voltage. This would give a lower-resistance starting motor, and, at first thought, this would require less battery volts at a required speed and torque. Actually, this is not the case. For example, tests on a generator, used to start an engine which required a firing torque of 200 pounds-feet at 200 rpm, showed the volt-ampere requirements given in Table I.

Although the amperes required are 13 per cent less, the voltage is 25 per cent greater with the commutating-field winding omitted and would require a higher-voltage battery. The reason for this is the familiar effect of an undercompensated commutating field reducing the speed of a motor. In the case of complete omission of the commutating-field excitation with the poles still in place, the undercompensating effect is very marked and produces the unfavorable change in required volts and amperes shown in Table I.

Conclusion

Generators having the mechanical features and the electrical performance described in this article are being applied to many sizes of industrial and railway switching locomotives at the present time. In addition to use on railroads and in industrial plants, many are being used by the Army and Navy in the United States and overseas. Others are being supplied to our allies. Their simplicity and reliability will be important factors in prompt movement of supplies and men in the many locations where they will be used.

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Diesel-Electric Switching-Locomotive Application by Means of Nomographic Charts

A. P. MILLAN
NONMEMBER AIEE

T. F. PERKINSON
NONMEMBER AIEE

Synopsis: The application of switching locomotives involves calculations of locomotive performance under given conditions of grade, train weight, and length of run. Such calculations can be made quickly by nomographic charts. Equipment heating limitations on Diesel-electric and electric locomotives can also be checked by elements added to the nomograms. The theory and the method of construction of such charts are described in the paper.

IN the process of determining applicability of Diesel-electric locomotives to railroad and industrial switching services, it is often necessary to determine whether or not the haulage of a given train up a grade of known length and severity is possible without exceeding the locomotive-equipment heating limitations.

The performance of such a haul is limited by wheel-to-rail adhesion, or by heating of the electric (traction motors and generators) or the engine equipment, or by both of these limitations.

Since switching service—be it industrial or railroad—usually comprises relatively short movements at full-load rating of the locomotive-engine equipment, coupled with idle periods, the engine equipment is, in general, applied on an intermittent-rating basis. Thus, a nominal 500-horsepower unit is suitable for sustained operation of the engine equipment at 500-horsepower output for but a limited period of time. This may be a period of one-half hour, or one hour, after which the load must be reduced to a fraction of the rating for a definite period of time before the nominal rating load can be carried again.

Likewise, the traction motors and generators are limited to definite-period loading, depending upon the heating characteristics of the machines under various conditions of loading.

The conventional speed–tractive-effort characteristic of the Diesel-electric switching locomotive, by itself, gives no information as to the service that can be performed with the locomotive without exceeding its equipment limitations, particularly in the high-tractive-effort low-speed portions of the characteristic where electric-equipment heating is limiting.

The speed–tractive-effort characteristic can be combined with the time-limitation characteristics, both of the engine and the electric equipment, on a nomographic chart which can be used to determine graphically and quickly whether or not a particular locomotive can handle safely a given train under known conditions of grade and length of grade.

The trailing tonnage that can be

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A. P. Millan is in the transportation division of General Electric Company, Boston, Mass., and T. F. Perkinson is with General Electric Company, Erie, Pa.

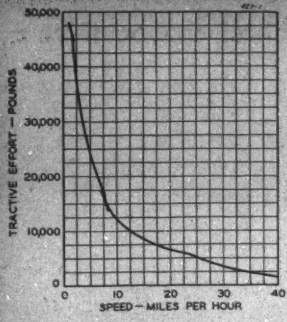

Figure 1. Speed–tractive-effort characteristic for 80-ton 500-horsepower Diesel-electric switching locomotive

handled by a locomotive at a definite speed on a given grade is determined by solution of the equation

$$W_t = \frac{T - W_L(R_L + 20G)}{(R_t + 20G)} \qquad (1)$$

in which

T = tractive effort in pounds of the locomotive at the given speed
R_L = resistance of the locomotive in pounds per ton of locomotive weight at the given speed
R_t = train resistance in pounds per ton of train weight at the given speed
W_t = weight of trailing train in tons
W_L = weight of locomotive in tons
G = grade in per cent

The train resistance varies with the individual weights of cars in the train, but, since unjustifiable complications in the calculations would be involved were this variation considered, a fixed value of train resistance based on experience is assumed in the following. This is taken at 8.5 pounds per ton. The value of R_L, resistance of the locomotive,[1] is, however, easily determined for different speeds by the equation

$$R_L = 1.3 + \frac{29}{W} + 0.03V + \frac{0.0024AV^2}{Wn} \qquad (2)$$

in which

R_L = resistance of locomotive in pounds per ton
W = weight per locomotive axle in tons
N = number of locomotive axles
V = speed in miles per hour
A = cross section of locomotive in square feet
= 105 for 50-ton locomotives
= 110 for 70-ton locomotives
= 120 for 100-ton locomotives

By means of the two equations, given in the foregoing, and the speed–tractive-effort characteristic curve applying to the particular locomotive (Figure 1 shows such a characteristic for a 500-horsepower 80-ton locomotive), a speed, grade, and trailing tons can be indicated as in Table I.

This table can be plotted in the form of a three-element nomogram with speed, grade, and trailing tons as the three elements. While the nomogram may be worked out analytically, the authors suggest that the graphical method of constructing the nomogram, as described in the following, is simpler and less tedious for those not skilled in setting up nomograms in general.

On any convenient size of paper the G scale is drawn in at the left-hand side of the paper, perpendicular to the base ordinate, while the W scale is erected perpendicular to the base line near the right-hand side of the paper (Figure 2). The authors suggest a minimum distance of 10 inches between the G and W scales and a length of 20 inches for the G and W scales for charts for locomotives up to 1,000-horsepower rating.

The W scale is marked off in a rectilinear scale, so that the maximum tonnage shown in Table I falls near the top of the sheet with the value of 0 tons at the base line.

On the G scale the value of 1.0 per cent grade is arbitrarily located one half of the length of the G-scale line above the base line. The value of zero per cent grade is taken at the base line.

The S scale is located as follows:

From the table select a value of tonnage that can be handled at a low speed—5.0 miles per hour—on level grade, and draw the construction line AB (Figure 2). From the table select a value of tonnage, corresponding to the same speed previously used—5.0 miles per hour in the present case—, that can be hauled on a 1.0 per cent grade. Draw the construction line CD. The intersection of AB and CD determines one point on the S scale. A second point corresponding to a higher speed can be determined in a similar manner when two combinations of speed, tonnage, and grade are selected from Table I. The S scale is then drawn in, as shown, as a straight line.

The G scale may be calibrated up to the maximum value of grade desired when the value of W is calculated for assumed values of G at 5.0 miles per hour by equation 1, and when the values of G are located on the scale by means of a straightedge from the value of W on the W scale through the 5.0 mile-per-hour point on the S scale.

Similarly, the S scale may be calibrated by laying a straightedge between the values of tonnage and grade given in Table I.

The upper end of the S scale may be taken at a speed point corresponding to 25 per cent adhesion tractive effort on the speed–tractive-effort characteristic. In the example selected 25 per cent of the locomotive weight is 40,000 pounds and the speed corresponding to this tractive effort from Figure 1 is 2.2 miles per hour.

The elements of the chart, which are required to indicate engine- and electric-equipment heating limitations, are added as described in the following procedure.

At the point on the S scale corresponding to 25 per cent adhesion speed, a perpendicular AB in Figure 3 is erected. Another line CD, Figure 3, is erected perpendicular to the S scale at the locomotive speed corresponding to the short-time limitation on the electric equipment which corresponds to the short-time limitation on the engine equipment. In the example selected, the engine equipment is limited to operation at 500 horsepower for 30 minutes, and the speed of 3.5 miles per hour corresponds to a 30-minute rating on the electric equipment for an initial winding temperature of 100 degrees centigrade and a final winding temperature (at the end of 30 minutes) of 160 degrees centigrade.

The point D is projected over to the line AB, parallel to the S scale to the point E. The line AE is then laid off on a logarithmic scale in minutes with the value of one at A and 30 at E.

The points F, G, and H are laid in on

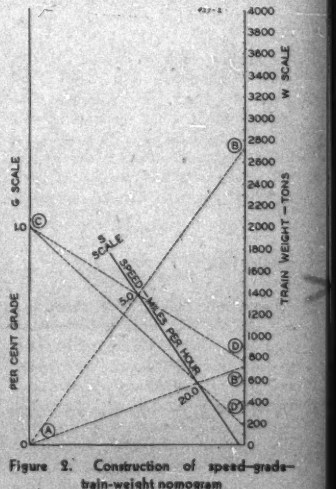

Figure 2. Construction of speed–grade–train-weight nomogram

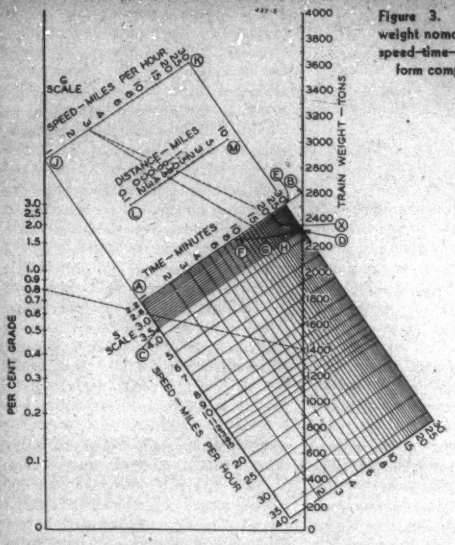

Figure 3. Speed–grade–train-weight nomogram combined with speed–time–distance nomogram to form complete working chart

Table I. Trailing Tonnages

Speed Miles Per Hour	Level	Per Cent Grade (Compensated) 0.5	1.0	1.5	2.0
3.3	3,737	1,674	1,057	762	588
5.0	2,767	1,227	768	547	418
7.5	1,923	840	516	361	270
10.0	1,420	609	367	251	182
15.0	974	404	234	152	104
20.0	731	292	161	98	61
25.0	540	204	104	56	28
30.0	340	113	45	12	
35.0	193	45			
40.0	100				

Resistance based on 8.5 pounds per ton, motors blown.

Tonnages do not include weight of locomotive.

the 10-, 15-, and 20-minute lines at the speeds corresponding to the tractive efforts to which these short-time ratings conform. The line *FGHD* indicates the limitations imposed by safe heating of the electric equipment.

The line *JK* is now drawn in as shown, perpendicular to the *S* scale at *J*, and calibrated in a log scale in speed in miles per hour with the value of one at *J* and the value of 30 directly opposite the 30-minute mark on *AB*.

The line *LM* is erected midway between *JK* and *AB* and calibrated in a log scale in miles fixing the 0.1-mile and 10-mile points with a straightedge laid between *JK* and *AB* at the points three miles per hour and two minutes (for 0.1 mile) and 30 miles per hour and 20 minutes (for ten miles).

The elements *AE*, *LM*, and *JK* are a nomographic plot of the equation

$$M = 0.01667 \times S \times T \qquad (3)$$

in which

M = distance in miles
S = speed in miles per hour
T = time in minutes

The chart is now ready for use.

As an example of its use, it is desired to determine whether the haulage of a 1,400-ton train up an 0.8 per cent grade one mile long will cause overheating of the engine or electric equipment on the 80-ton 500-horsepower locomotive for which the chart has been drawn.

A straightedge laid between 0.8 on the *G* scale and 1,400 on the *W* scale crosses the *S* scale at 2.8 miles per hour.

A straightedge laid across the points 2.8 on line *JK* and 1.0 on line *LM* intersects the time scale at 21.5 minutes. A line drawn from 2.8 on, and perpendicular to, the *S* scale intersects the 21.5-minute line at *X*, and, since this point lies above the electric-equipment heating line *FGHD*, the indication is that the electric equipment will be overheated in performing the given service. It may be noted that the line from 2.8 miles per hour on the *S* scale to *X* intersects the line *FGH* at 14 minutes. A straightedge, laid between the 14-minute point on line *AB* and the 2.8 point on *JK*, intersects the *M* scale at 0.66 mile, indicating that haulage of the 1,400-ton train on an 0.8 per cent grade should be limited to a distance of 0.66 mile, if the electric equipment is not to be overheated.

By obvious cut-and-try methods it can be determined that a train of 1,285 tons trailing is the maximum that can be handled on the 0.8 grade, one mile in length, without exceeding the permissible temperature rise in the electric equipment.

If the intersection of the speed line from the *S* scale with the time line falls below the electric-equipment heating-limitation line, but to the right of the 30-minute line, overheating of the engine equipment is indicated.

If the straightedge between the *G* scale and *W* scale falls across the *S* scale at a point above and to the left of the point *A*, a high value of adhesion (greater than 25 per cent) and the likelihood of wheel slippage are indicated.

Reference

1. Tractive Resistance of Electric Locomotives and Cars. W. J. Davis, Jr. *General Electric Review*, October 1926.

Symmetrical-Components Analysis of the Four-Phase System

A. BOYAJIAN
FELLOW AIEE

Synopsis: Symmetrical-components concepts are developed for the currents, voltages, and impedances of a four-phase system, and formulas are given for various types of short circuits. The idea of symmetry among the members of each set is based on the angular displacement between the members of the set, rather than that of phase rotation which fits the three-phase case very nicely but is inadequate for the four-phase case.

Aside from its possible value for four-phase problems, which are rather rare, the paper is presented here in the expectation of an additional benefit, namely, that the parallelisms and contrasts between the four-phase and the three-phase formulas may throw further light on the general theory and applications of symmetrical components.

THE highly developed automotive art—model of American efficiency in production—has taught the public to expect that the factory must be specially tooled up for each new model. The philosophy of tooling is such common knowledge in the mechanical arts that, even though many an operation could be carried out with hammer, file, and screw driver, many a mechanic will frequently be seen making a special tool for an odd operation, as requiring less time in the end. The same philosophic principle holds in all the arts, electrical as well as mechanical; and such an experience in electrical engineering, with a conscious philosophy of tooling, led to the work which forms the subject matter of this paper.

The author had occasion to analyze the performance characteristics of an existing two-phase system if converted to a five-wire four-phase system. The attempt was made first by elementary methods, using such common tools as Kirchhoff's laws, but the problem involved unknown mutual impedances, and additionally the equations tended to be lengthy and burdensome, and each new problem meant going through a similar distasteful operation all over again. It was then thought that on the whole the work would be much less and the results more dependable if a tool was developed in the form of a four-phase symmetrical-components method of analysis. This was done, and the results fully justified the expectations. The analysis became very systematic and straight forward; the impedances, such as could be estimated with some confidence; and the resulting formulas, such as could be interpreted and checked physically. It was then thought that it might be worth while to put this sytem of analysis on public record, not only for use on those few occasions when four-phase system problems may be encountered, but also for its technical and educational value, as a further illustration of the power of the symmetrical-components concept as a tool in the analysis of electrical systems.

Those familiar with the three-phase technique will be interested in observing the resemblances and the differences between the three-phase and the four-phase techniques.[1-3]

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A. BOYAJIAN is electrical engineer, power-transformer engineering division, General Electric Company, Pittsfield, Mass.

Concept of Symmetrical Components in the Four-Phase System

The conventional concept of symmetrical components of three-phase system—positive-negative-, and zero-phase-sequence components—is peculiar to the three-phase circuit and not very adaptable to a system with greater number of phases, because a four-phase system must have four components (n-phase system n components), and the concept of positive-, negative-, and zero-phase-sequence components offers us no clue as to how to find an appropriate fourth component for the four-phase system.

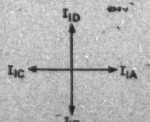

Figure 1. Symmetrical set of vectors, I_1

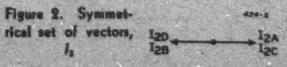

Figure 2. Symmetrical set of vectors, I_2

If, instead of considering the direction of rotation as the distinguishing mark of a symmetrical set of vectors, we consider the magnitude of the characteristic angle between the vectors of the adjacent phases as the distinguishing mark, we obtain a rule that enables us to define the symmetrical components of a system of any number of phases. Thus, if the angle between adjacent phases is θ for the normal symmetrical set of vectors of the system, then a set in which the vectors succeed each other at intervals of 2θ constitutes a second symmetrical set; one with intervals of 3θ, a third symmetrical set; and so forth. The negative-sequence set of the three-phase system corresponds to the set having the characteristic angle of 2θ. Since, in the n-phase system, θ equals $360/n$ degrees, the nth set of symmetrical vectors will have the characteristic angle $n(360/n)$, or just 360 degrees, which is equivalent to zero; that is, all of the vectors will be in phase with each other, like the zero-phase-sequence set of the three-phase system. The set $(n+1)$ turns out to be a duplication of set 1, $(n+2)$ a duplicate of set 2, and so forth, so that the n-phase system has only n distinct symmetrical components.

Accordingly, in a four-phase system (Figure 5), the consecutive phases of the normal symmetrical set of vectors I_1 are spaced 90 degrees apart (Figure 1); those of set I_2, 2×90 degrees or 180 degrees apart (Figure 2); those of set I_3, 3×90 degrees or 270 degrees apart (Figure 3); and those of set I_4, 360 degrees, or what is equivalent to it, 0 degrees apart (Figure 4).

Evidently, the set I_1 (Figure 1) corresponds to the positive-phase-sequence set of three-phase systems: the set I_3 (Figure 3), to the negative-phase-sequence set; and the set I_4 (Figure 4), to the zero-phase-sequence set; but there is nothing like the set I_2 (Figure 2) in a three-phase system. The set I_2 has a similarity to the set I_4, except for the important difference that, instead of a neutral return, the horizontal phases act as return to the vertical phases, and vice versa.

The difference in concepts leads also to a difference in notation. If we wish the subscript to represent the characteristic angle, then the set of vectors in Figure 3,

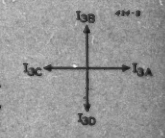

Figure 3. Symmetrical set of vectors, I_3

Table I. Impedance Data

	Bank G 7,500-Kva Base (Per Cent)	Bank U 7,500-Kva Base (Per Cent)	Primary Lines 15,000-Kva Base (Per Cent)	Total 15,000-Kva Base (Per Cent)
Z_1	6.4	6.4	2.4	8.8
Z_2	75	75		75
Z_3	6.4	6.4	2.4	8.8
Z_0	75	Infinity		150

with the characteristic angle 3θ, is correctly marked as I_1; whereas, if phase rotation were to be the guide, we would have had to mark it I_3, and the set I_4 as I_3, conforming to the conventional notation for the negative- and zero-phase-sequence components of the three-phase circuit. This author feels that the three-phase notation is about as poorly adapted as the three-phase concept to the four-phase circuit, but, inasmuch as I_n has zero characteristic angle in all systems, we may use the conventional symbol I_0 for it. So in what follows, we shall refer to I_4 and E_4 as I_0 and E_0.

Impedances to Sequence Currents

The types of symmetrical sets of currents already defined, and illustrated in Figures 1–4, define also the corresponding impedances (Z_1, Z_2, Z_3, Z_0) for a four-phase system.

(*a*). Z_1 is the impedance of the circuit to the normal balanced four-phase currents of Figure 1. It is independent of the condition of the neutral—whether it be grounded or isolated, and even whether the mid-point of the vertical windings is joined with that of the horizontal windings. Phase A, however, must be joined with C, and B with D.

(*b*). Z_2 is the impedance offered to currents like those in Figure 2. As the horizontal and the vertical phases act as return circuits to each other, their mid-points must be tied together. Otherwise Z_2 will be infinity. The grounding or isolation of the common neutral makes no difference to Z_2. Z_2 can be measured with single-phase voltage, connecting A to C as one terminal, and B to D as the other. The result must, of course, be expressed per phase.

To secure a low value of Z_2, opposite phases must be well interlaced or closely coupled with each other. Depending on the presence or absence of such treatment in transformers, Z_2 may be as low as $Z_1/10$, or as high as 10 Z_1.

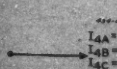

Figure 4. Symmetrical set of vectors, I_0

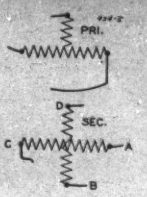

Figure 5. Four-phase supply system—three-phase primary, four-phase secondary connections

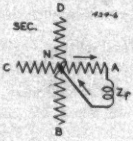

Figure 6. Single-phase load, line-to-neutral

(*c*). Z_3 is the negative-phase-sequence impedance and has the same value as Z_1 for static circuits.

(*d*). Z_0. If Figure 4 is compared with Figure 2, there is a certain similarity in the flow of currents, I_3 and I_0, by virtue of which, Z_0 may have the same, or approximately the same, value as Z_2. The important case in which this would not be true at all is the case of the isolated neutral, in which case I_0 cannot flow, and Z_0 must then be set down as infinity, while Z_2 may still have a very low value.

In most of the practical instances, therefore, the four-phase system is likely to have only two independent, impedances, Z_1 and Z_0; although, in the general case, the static system will have three independent impedances, Z_1, Z_2, and Z_3; and the rotating machine, four.

In all of these cases, it is necessary to assume that, for any one set of currents, the corresponding set of impedance drops are also symmetrical in the same sense as those currents. If this is far from true, the value of symmetrical-components method of analysis is greatly reduced.

Symmetrical Components of Unsymmetrical Four-Phase Currents

Representing the four phases by letters, the symmetrical components by numbers, and with phase A as the reference phase,

$$I_1=I_{1A}=(I_A+I_B/90°+I_C/180°+I_D/270°)/4 \quad (1)$$

$$I_2=I_{2A}=(I_A+I_B/2\times90°+I_C/2\times180°+I_D/2\times270°)/4 \quad (2)$$

$$I_3=I_{3A}=(I_A+I_B/3\times90°+I_C/3\times180°+I_D/3\times270°)/4 \quad (3)$$

$$I_0=I_{4A}=(I_A+I_B/4\times90°+I_C/4\times180°+I_D/4\times270°)/4 \quad (4)$$

and inversely

$$\left.\begin{aligned}
I_A&=I_1+I_2+I_3+I_0\\
I_B&=I_1/90°+I_2/2\times90°+I_3/3\times90°+I_0/4\times90°\\
&=I_1/90°-I_2+I_3/90°+I_0\\
I_C&=I_1/180°+I_2/2\times180°+I_3/3\times180°+I_0/4\times180°\\
&=-I_1+I_2-I_3+I_0\\
I_D&=I_1/270°+I_2/2\times270°+I_3/3\times270°+I_0/4\times270°\\
&=I_1/90-I_2-I_3/90+I_0
\end{aligned}\right\} \quad (4.1)$$

These accord with Figures 1–4.

Equations analogous to 1–4.1 apply also to voltages.

We now apply these formulas to some representative unsymmetrical cases for use in short-circuit calculations.

Single-Phase Load From One Line to Neutral: A–N

As line A (Figure 6) is the only one with current, all others zero,

$$I_A=I_A \text{ (given)}; \; I_B=0; \; I_C=0; \; I_D=0$$

Therefore, in applying formulas 1–4, only the first term on the right needs consideration, and we obtain the result

$$I_1=I_A/4; \; I_2=I_A/4; \; I_3=I_A/4; \; I_0=I_A/4 \quad (5)$$

That is, in the loaded phase (phase A), all four components are equal and in phase. It can be verified that in the adjacent phases (B and D, idle), I_3 cancels I_0, and I_1 cancels I_2. In the opposite phase (C, also idle), I_1 cancels I_0, and I_3 cancels I_2. These relationships find a significance in the calculation of voltage drops. If the corresponding impedances are alike, where the currents cancel, so will the voltages; but, if the impedances are dissimilar, a net voltage change (with no net current) will result.

Table II

		Grounded Bank	
		Phase A (Per Cent)	Phase C (Per Cent)
(1)	I_1Z_1 (1.65/4)	8.8 = 3.63	3.63
(2)	I_2Z_2 (1.65/4)	75 = 31	−31
(3)	I_3Z_3 (1.65/4)	8.8 = 3.63	3.63
(4)	I_0Z_0 (1.65/4)	150 = 62	−62
(5)	Total Drop	100	−85.7

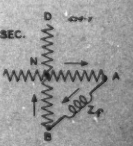

Figure 7. Single-phase load, line-to-line

SINGLE-PHASE LOAD ACROSS ADJACENT LINES: *A–B*

It is seen from Figure 7 that

$$I_A = I_A \text{ (given)};\quad I_B = -I_A;\quad I_C = 0;\quad I_D = 0$$

Hence, only the first two right-hand terms of formulas 1–4 count, and we obtain the results

$$\left.\begin{aligned} I_1 &= \frac{1}{2\sqrt{2}} I_A \underline{/45^\circ} && \text{(a)}\\ I_2 &= \frac{1}{2} I_A && \text{(b)}\\ I_3 &= \frac{1}{2\sqrt{2}} I_A \underline{/45^\circ} && \text{(c)}\\ I_0 &= 0 && \text{(d)} \end{aligned}\right\} \quad (6)$$

SINGLE-PHASE LOAD ACROSS OPPOSITE LINES: *A–C*

From Figure 8

$$I_A = I_A \text{ (given)};\quad I_B = 0;\quad I_C = -I_A;\quad I_D = 0$$

By equations 1–4

$$\left.\begin{aligned} I_1 &= 0.5 I_A\\ I_2 &= 0\\ I_3 &= 0.5 I_A\\ I_0 &= 0 \end{aligned}\right\} \quad (7)$$

Formulas for Fault Currents and Voltages

LINE-TO-NEUTRAL SHORT CIRCUIT: *A–N*

If the load in Figure 6 is treated as a short circuit, the entire phase voltage E_{NA} is then consumed by the total impedance drop in phase *A*. Hence

$$\vec{E_{NA}} = I_1 Z_1 + I_2 Z_2 + I_3 Z_3 + I_0 Z_0$$

If the values of I_1, and so forth, are substituted from equation 5,

$$E_{NA} = I_A (Z_1 + Z_2 + Z_3 + Z_0)/4 \quad (8)$$

As I_A is now I_{fault}, therefore

$$I_{fault} = 4E_{NA}/(Z_1 + Z_2 + Z_3 + Z_0) \quad (9a)$$

and for static circuits

$$= 4E_{NA}/(2Z_1 + Z_2 + Z_0) \quad (9b)$$

If the fault has an impedance Z_f, an impedance Z_f may be assumed in series with each one of the open lines also for symmetry, in which case each one of the impedances $Z_1, \ldots, Z_0$ will be increased by Z_f, changing equation 9a into equation 10

$$I_f = 4E_{NA}/(Z_1 + Z_2 + Z_3 + Z_0 + 4Z_f) \quad (10)$$

Another way of considering the fault impedance in this case is as one connected in series with the neutral, carrying a current $4I_0$, in which case, Z_1, Z_2, Z_3 are not affected, but Z_0 is increased by $4Z_f$, leading again to equation 10.

This equation 10 may be compared with that of the three-phase case, namely

$$I_{fault} = 3E_{NA}/(Z_1 + Z_2 + Z_0 + 3Z_f) \text{ in conventional notation} \quad (11)$$

The equivalent-sequence network of the four-phase circuit under consideration is shown in Figure 9. It follows from equations 9 and 10.

If we apply normal phase voltage (line-to-neutral) to this network, the resulting current is one of the sequence currents (all alike in phase *A*); if we apply four times that voltage, the resulting current is the fault current.

Equations 9 and 10 hold equally in absolute values or in per unit values, also in percentage values, in which latter case, however, the fault current is in terms of "times normal."

To illustrate the calculation of the terminal voltages under fault condition, V_{NB} will be seen to be given by equation 12 as the open-circuit voltage minus the four impedance voltages of phase *B*

$$\vec{V_{NB}} = \vec{E_{NB}} - (I_1 \underline{/90^\circ} Z_1 + I_2 \underline{/180^\circ} Z_2 + I_3 \underline{/270^\circ} Z_3 + I_0 \underline{/360^\circ} Z_0) \quad (12)$$

LINE-TO-ADJACENT-LINE SHORT CIRCUIT: *A–B*

In the light of Figure 7, if the load is treated as a short circuit, it will be seen that the open-circuit voltage $\vec{E_{BA}}$ is consumed by the impedance voltage in phase *A* minus the impedance voltage in phase *B*. And as $\vec{E_{BA}}$ is equal to $\sqrt{2}\,\vec{E_{NA}}\underline{/45^\circ}$, therefore

$$\vec{E_{BA}} = (I_1 Z_1 + I_2 Z_2 + I_3 Z_3 + I_0 Z_0) - (I_1 Z_1 \underline{/90^\circ} + I_2 Z_2 \underline{/180^\circ} + I_3 Z_3 \underline{/270^\circ} + I_0 Z_0 \underline{/360^\circ})$$
$$= \sqrt{2} I_1 Z_1 \underline{/45^\circ} + 2 I_2 Z_2 + \sqrt{2} I_3 Z_3 \underline{/45^\circ} + 0 \quad (13)$$

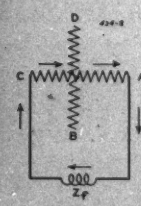

Figure 8. Single-phase load, across opposite lines

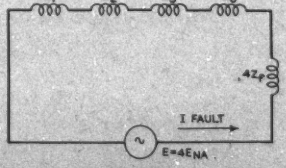

Figure 9. Equivalent sequence network of Figure 6

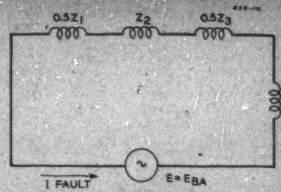

Figure 10. Equivalent sequence network of Figure 7

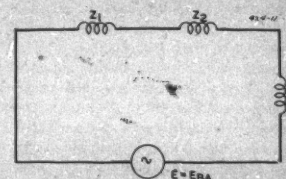

Figure 11. Equivalent sequence network of Figure 7 for static circuits only

If the values of $I_1, \ldots, I_0$ are substituted from equation 6

$$E_{BA} = I_A (0.5Z_1 + Z_2 + 0.5Z_3) \quad (14)$$

Hence

$$I_{fault} = E_{BA}/(0.5Z_1 + Z_2 + 0.5Z_3) \quad (15a)$$
$$= E_{BA}/(Z_1 + Z_3) \text{ for static circuits} \quad (15b)$$

If the fault itself has the impedance Z_f, half of it may be assumed as in series with line *A*, the other half in series with line *B*; and for the sake of symmetry, a $Z_f/2$ may be assumed as existing also in series with each one of the open lines *C* and *D*, so that each one of the four sequence impedances $Z_1, \ldots, Z_0$ is increased by $Z_f/2$, and formulas 15 are transformed to 16.

$$I_{fault} = E_{BA}/(0.5Z_1 + Z_2 + 0.5Z_3 + Z_f) \quad (16a)$$
$$= E_{BA}/(Z_1 + Z_3 + Z_f) \text{ for static circuits} \quad (16b)$$

Z_f could have been inserted in equation 16 by inspection, without reference to symmetrical components, but the reasoning in the preceding paragraph is given to illustrate a principle and a method.

The sequence network of this is shown in Figure 10 (and 11), except that it

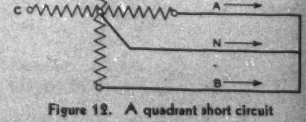

Figure 12. A quadrant short circuit

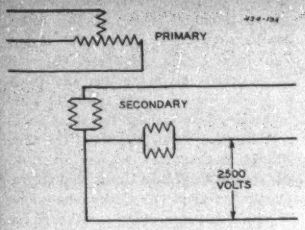

Figure 13A. Three-phase to quarter-phase connected transformer bank

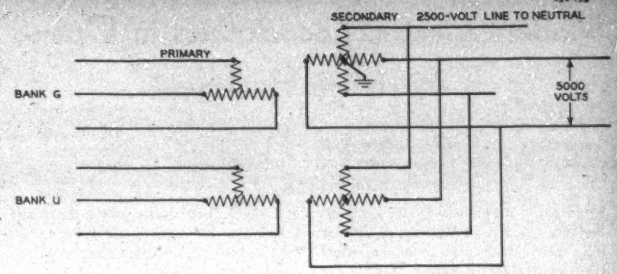

Figure 13B. Two banks of transformers in three-phase to four-phase connection

Bank G neutral-grounded; U ungrounded

represents only I_f or I_3 properly—I_f if E_{BA} is impressed, I_3 if half that voltage is impressed—but not I_1 or I_3, as a consideration of equation 6 will make clear. Sequence networks may have such limitations.

If the resultant voltages under the fault conditions are required, the same reasoning as in equation 12 applies to the neutral-to-line voltages; and the line-to-line voltages follow from neutral-to-line voltages as in

$$\overrightarrow{V_{CB}} = \overrightarrow{V_{NB}} - \overrightarrow{V_{NC}} \qquad (16c)$$

LINE-TO-OPPOSITE-LINE SHORT CIRCUIT: A–C

In the light of Figure 8 and equations 7

$$E_{NA} = I_1Z_1 + I_2Z_2 + I_3Z_3 + I_0Z_0$$
$$= 0.5I_A(Z_1 + Z_2) \qquad (17)$$
$$I_{fault} = 2E_{NA}/(Z_1 + Z_2) \qquad (18a)$$
$$= E_{NA}/Z_1 \text{ for static circuits} \qquad (18b)$$

The last is an obvious result, though not equation 18a.

The sequence network is evident from equation 18a.

A QUADRANT SHORT CIRCUIT: A–B–N

Case 2, involving lines A and B, did not involve the neutral, but, in this case, lines A and B are short-circuited to the neutral (Figure 12). Now there are three different fault currents: I_A, I_B, I_N. As I_N is the (negative) vector sum of I_A and I_B, and as I_A and I_B (as well as I_C and I_D) are the resultants of the sequence currents, the independent unknowns may still be taken as $I_1, \ldots, I_0$, and the equations defining them are

$$\left.\begin{aligned}
E_{NA} &= I_1Z_1 + I_2Z_2 + I_3Z_3 + I_0Z_0 && \text{(a)}\\
E_{NB} &= I_1Z_1/\underline{90°} - I_2Z_2 + I_3Z_3/\underline{270°} + I_0Z_0 && \text{(b)}\\
I_C = 0 &= I_1\sqrt{\underline{180°}} + I_2 + I_3/\underline{180°} + I_0 && \text{(c)}\\
I_D = 0 &= I_1/\underline{90°} - I_2 + I_3/\underline{90°} + I_0 && \text{(d)}
\end{aligned}\right\} \qquad (19)$$

These can be solved perhaps more easily numerically, substituting the values of the impedances, the two known currents (0), and the two known voltages (1 or 100 per cent).

The foregoing cases will illustrate how to proceed in the solution of other combination short circuits. Generally, the sum of the known voltages (consumed) and the known currents (zero) will be four, the same as the number of the unknowns, $I_1, \ldots, I_0$, and therefore sufficient to solve the problem.

Example

Each one of two banks of three-phase to two-phase transformers is connected up as in Figure 13a. The secondary (two-phase) windings of each single-phase transformer are seen to be two in parallel, connected up for 2,500 volts. We wish to investigate the characteristics of the system if the two-phase coils are connected up in series for 5,000 volts and arranged four phase (Figure 13b) with the neutral of only one bank (G) grounded, the other (U) ungrounded.

The impedance data are as shown in Table I. The high value of Z_2 for the transformers arises from the fact that originally no loading of the mid-point of the secondary windings in 5,000-volt connection was contemplated, and therefore no provision was made to interlace the two halves. No values are entered for Z_3 for the primary lines because there is no current in them corresponding to I_3 in the secondary lines. For bank G, Z_0 is entered as equal to Z_2, while for bank U it is entered as infinity because the neutral of this bank is ungrounded. While, in the design of the transformers, Z_2 and Z_0 are alike, yet in the system as a whole (last column) Z_0 has double the value of Z_2 on account of the particular neutral treatment—one bank neutral-grounded, the other bank neutral-isolated. These figures are all reactance values, the resistance components being ignored here as relatively small.

Currents

The value of the single-phase fault current, from one line to neutral, by equation 9 will be seen to be

$$I_{fault} = 4 \times 100/(8.8 + 75 + 8.8 + 150)$$
$$= 400/243$$
$$= 1.65 \text{ times normal, based on 15,000 kva}$$

The components I_1, I_2, and I_3 divide equally between the two banks, but I_0 flows exclusively in bank A (with grounded neutral). As all components are equal in the fault, the current in the faulty phases (A) of the two banks will be

Bank G, $I_A = 2(5/8)1.65$ times transformer rating
$= 2.06$ times transformer rating
Bank U, $I_A = 2(3/8)1.65$ times transformer rating
$= 1.24$

Voltages

The important question about the voltages is particularly the drops through the large Z_1 and Z_0. A view of all four sequence drops is given in Table II.

In item 5 the negative voltage drop of 85.7 per cent means that, under the fault, the voltage of phase C rises to 185.7 per cent. Evidently this implies supersaturation of the core leg of phase C in bank G.

The voltages of the other phases of this or of the other bank can be similarly calculated (remembering that I_0 is zero for bank U).

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Modern Electric Locomotives in Open-Pit Mine Haulage

J. E. BORLAND
NONMEMBER AIEE

L. G. RILEY
NONMEMBER AIEE

EARLY in 1942 Phelps Dodge Corporation started production of copper from their new open-pit mine and reduction plant at Morenci, Ariz. One of the earliest mining districts of the state, Morenci had produced some 900,000 tons of copper since the beginning of operations in the early 70's, largely from ores of two to three per cent copper content, mined underground.

The ore body now opened had been explored from the earlier underground workings, and by churn and diamond drilling. It is estimated to contain 230,000,000 tons of ore averaging slightly over one per cent copper, capable of profitable recovery by open-pit mining, concentration, and smelting. The new operation, therefore, will produce more than twice the amount of copper previously taken from the district. In the extraction of this ore, approximately an equal amount of barren capping and slightly mineralized rock throughout the ore body will have to be removed and hauled to lean-ore dumps or to waste dumps in canyons adjacent to the mine.

Preliminary development to uncover sufficient ore and prepare the mine for the planned initial production of 25,000 tons of ore a day was started in 1937. This preparatory development included the removal of some 50,000,000 tons of material, establishment of benches in the mine area, construction of truck haulage roads and standard-gauge railroad for ore and waste haulage. In the first stages this work was handled mainly with 4 $4^1/_2$-yard full-revolving electric shovels and 18 $22^1/_2$-yard end-dump trucks. Later, with the formation of benches and construction of roadbed, rail was laid in the mine, and the main-ore and waste haulage tracks were installed, permitting the work to be taken over largely by trains of 30-yard side-dump cars. Four 125-ton Diesel-electric locomotives with engines of 1,000 horsepower sea-level rating, were put on trial and used in this service, and in the latter stages the 125-ton electric locomotives that had been selected for main-ore haulage were utilized.

In the initial development, 11 mining benches were opened in the ore body, at a uniform height of 50 feet and average width of 100 feet, laid out at even elevations above sea level, the lowest at 4,750 feet and the highest at 5,250 feet. Benches vary in length up to approximately 4,000 feet. Ultimately the pit will be developed to a maximum length of 5,800 feet and will cover 350 acres. The lowest level to be worked will be the 4,200 and the highest the 5,500.

The nearest suitable location for the reduction plant in the rugged terrain of the district was a comparatively level section southeast of the mine. At this site the ore haulage tracks at the primary crusher were established at an elevation of 4,480 feet. From the nearest point of exit from the mine to the crusher the straight-line distance is about 1.8 miles, but the high hills and the town of Morenci lying between these points necessitated a considerably greater length of ore haulage track.

In the early part of the development period, analyses were made of the costs of ore and waste haulage for the planned maximum production of 40,000 tons of ore a day, based on operation on maximum grades of 3.4, 4 or 6.5 per cent. With the decision to limit the maximum grade to four per cent, construction of the track roadbed from the mine to the crusher was started.

The plan of ore and waste haulage tracks at the start of production was approximately as shown by Figure 1; some alterations have since been made. A series of switchbacks on a descending grade of four per cent, compensated for curvature, lead from the mine for nearly two miles to a section of 0.4 per cent descending grade a little less than a mile in length, terminating in a 0.4-mile level-approach track to the primary crusher. Successive mining benches are connected at the ends nearest the ore haulage tracks by switchbacks on four per cent grade. From the opposite ends of the benches tracks on maximum grade of 3.5 per cent lead to approach tracks to four waste dumps in Coronado Canyon and one in Fairbanks Gulch, adjoining the pit. Dump tracks are on 0.25 per cent grade at elevations of 4,800 to 5,200 feet. Something over half of the total waste rock disposal during the life of the mine will be in Coronado Canyon, about 13 per cent in Fairbanks Gulch, and the remainder in Chase Creek Canyon, along the main-ore haulageway. Although the track elevation at the crusher, 4,480 feet, is about midway between the present and the final lowest mining bench, 4,750 feet and 4,200 feet respectively, it is estimated that 85 per cent of all material will be hauled over favorable grades.

Main-ore haulage tracks are laid with 131-pound rail, standard-gauge; bench and waste-dump tracks with 90-pound rail. Double track provided on the main-ore haulage road and passing tracks are not shown in Figure 1.

Comparisons were made of the amount of equipment required and the operating costs for ore haulage with solid-body or side-dump cars of different capacities,

Table 1. Ore-Haulage Schedule for Locomotives in Continuous Operation Between Mining Bench (4,950 Feet) and Crusher

Number of cars in train	11
Weight of empty car	38.5 tons
Weight of ore load in car	90 tons
Running time with loaded train, down hill, from end of temporary track on 4,950-foot bench to crusher	31 minutes
Running time with empty train uphill, from crusher to start of temporary track on 4,950-foot bench	24 minutes
Delay of one minute at each of 4 switchbacks in each direction	8 minutes
Assuming locomotive switches to empty train at crusher and to loaded train at bench:	
Switching time at crusher	2 minutes
Switching time at bench	2 minutes
Total time of round trip	67 minutes

and with trains of different numbers of cars. These analyses were based on hauling 25,000 tons of ore in two eight-hour shifts, at the maximum train speeds considered permissible on the several sections of permanent, semipermanent, and temporary track, on an expected maximum average loading capacity of 6,050 tons in eight hours by each $4^1/_2$-cubic-yard electric shovel, and at a maximum dumping rate of 3,400 tons per hour at the primary crusher. Although they indicated a greater investment for equipment and higher energy consumption with side-dump cars in ore haulage, there were compensating advantages in simplification of mine operation and train dispatching by the use of cars of the same type in both ore and waste-haulage service, and in elimination of the large car

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J. E. BORLAND and L. G. RILEY are with Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Table II. Maximum Train Speeds Considered Permissible on Various Track Sections

	Miles Per Hour
On temporary track and switchbacks	8
Fast track from crusher to elevation 4,500:	
Upgrade	25
Downgrade	18
Other permanent track:	
Upgrade	15
Downgrade	12

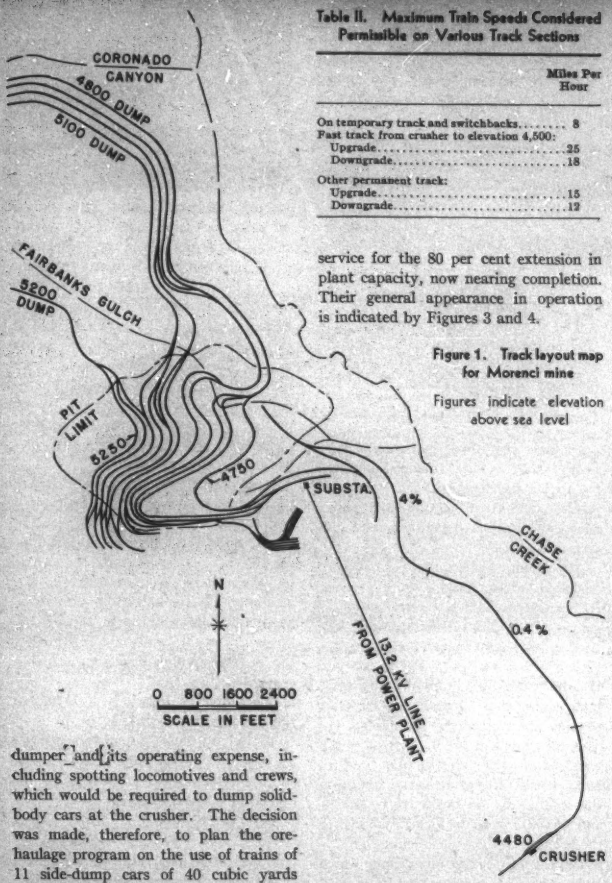


Figure 1. Track layout map for Morenci mine

Figures indicate elevation above sea level

dumper and its operating expense, including spotting locomotives and crews, which would be required to dump solid-body cars at the crusher. The decision was made, therefore, to plan the ore-haulage program on the use of trains of 11 side-dump cars of 40 cubic yards capacity each.

Analyses were made also of the initial investments, operating costs and other features of ore and waste haulage with:

(*a*). Diesel-electric locomotives.

(*b*). Electric locomotives for operation from a 750-volt trolley circuit, using power from the projected 50,000-kw turbine generating plant at the reduction works. Previous estimates on a 1500-volt system had shown no advantage over 750 volts in this service and had confined further considerations to the lower voltage.

Electric Locomotives

In the final analysis, electric locomotives were selected for main-ore and waste haulage at Morenci. Nine locomotives were placed in service during 1941 for the initial production of 25,000 tons of ore a day, and seven more are in service for the 80 per cent extension in plant capacity, now nearing completion. Their general appearance in operation is indicated by Figures 3 and 4.

Operating Voltage

The locomotives are designed for operation at a nominal-contact trolley-line voltage of 750 volts direct current and a maximum voltage of 900 volts at no load in the mercury-arc-rectifier substations supplying the trolley circuit.

Locomotive Weight and Haulage Capacity

The locomotive weight of 125 tons was selected to permit hauling the maximum train of 11 38.5-ton empty cars up the four per cent grades with an estimated adhesion of slightly over 19 per cent, and to provide by electric braking over 40 per cent of the retarding effort required with trains of 11 128.5-ton loaded cars descending the four per cent grades. The cars in use have an empty weight of approximately 45 tons and carry from 90 to 100 tons of ore or waste.

To insure adequate capacity for the most severe duty that might be imposed in haulage service co-ordinated with the maximum rates of loading by $4^1/_2$-cubic yard electric shovels and dumping at the primary crusher, the locomotives are capable of maintaining continuous operation between the mining bench at 4,950 feet elevation and the crusher on the ore-haulage schedule shown in Table I.

The maximum train speeds considered permissible on various track sections are shown in Table II.

Bench Operation

Although it is practicable to operate electric locomotives from temporary trolley structures on the mining benches, in order to free operations of any impediment from such structures in the mining areas and to avoid the delay and expense of maintaining and moving them in the progress of mining, it was deemed advisable to make other provision for train movements on bench track. Alternative arrangements considered were:

(*a*). Cable reel on the locomotive for power supply on bench tracks beyond the ends of electrified sections. Such operation was somewhat dubious because of the great lengths to which the mine benches will extend, the slow speeds necessary when operating on cable reel paid out from the locomotive, and the probability of rapid wear and short life of cable in such service.

(*b*). Auxiliary Diesel-engine–generator set on the locomotive to supply power for train movements on unelectrified bench tracks. Because of the increased cost of an auxiliary unit of sufficient power for satisfactory movement of loaded and empty trains on bench tracks, and the operating complications which would be introduced, this arrangement was concluded to be undesirable.

(*c*). A storage battery on the locomotive of sufficient capacity for train movements at the desired speeds on the benches was decided to be worthy of trial.

Each locomotive is equipped with a storage battery applied for an expected life of approximately five years. The most severe duty cycle on the battery for train movements on benches was estimated to be for power supply in the following operations:

Hauling a train of 11 empty cars from the start of temporary track on the 4,950 foot bench to the far end, a distance of 4,000 feet, in approximately $5^1/_2$ minutes.

Spotting 11 cars at the shovel for loading at the rate of 15.75 tons per minute.

Accelerating the train of 11 loaded cars at a maximum rate of 0.1 mile per hour per

second and hauling it back to the trolley at the start of permanent track in approximately 6¼ minutes.

Operating air compressor for braking service, and supplying lighting, heating, and control circuits.

The 240-cell 500-volt lead-acid storage battery applied to each locomotive has a discharge capacity of 500 ampere-hours on a six-hour basis, approximately 70 per cent of the estimated output required for six complete bench cycles in average duty. The complete battery weighs approximately 14 tons.

A large part of the battery output in each bench cycle is restored during the succeeding interval of time in which the locomotive is operating under the trolley to the crusher with loaded train, while dumping cars and when returning the empty train to a mine bench. Automatic charging equipment on the locomotive connects the battery to the trolley circuit through suitable resistors, providing at the start a high charging rate and later a reduced rate when the battery charge has been restored to a predetermined value.

With the locomotives in service for three eight-hour shifts each day, the batteries automatically are returned to full charge during the runs to and from the crusher. Under other conditions, such as waste-haulage and dump operation, occasional lay-up for recharging is necessary. Periodic equalizing charging is also regular practice. A lay-up track is provided at the mine pit shops for recharging from the trolley wire, and the batteries automatically are disconnected at full charge. Daily gravity readings are taken to check battery conditions.

As it is expected that, after some years of further development of the mine, the frequency of movement of bench tracks will be less than that necessary in present operation, and it later may become advantageous to operate from portable trolley over the bench tracks, all locomotives are arranged for the addition of side-arm collectors, when desired.

Figure 2. General view of the mine pit and benches, showing progress made early in 1943

Electric Braking

Studies were made of the merits of regenerative braking or dynamic braking on the locomotives to assist the straight or automatic air brakes in retarding loaded trains on descending grades, and thereby reduce wheel and brake-shoe wear and maintenance and replacement costs. The decision to adopt dynamic braking was based mainly on the lower cost and relative simplicity of locomotive and substation equipment.

The dynamic brake on each locomotive is capable of producing retarding efforts up to 50,000 pounds at train speeds between 8 and 18 miles per hour.

Construction of Locomotives

Haulage conditions encountered in a project such as the Morenci mine have led to the development of a locomotive specially adapted to this duty. Figure 5 shows the general dimensions and construction.

The running gear consists of two four-wheeled trucks, having welded steel frames supported by a combination of coil and half elliptic side springs. The trucks are permanently coupled together with a mallet or ball hinge, and the drawheads are built into the truck bumpers, so that all draft and bumping stresses are continuous throughout the running gear and are not in any way transmitted to the cab structure. Articulated trucks are particularly suited to the severe duty on rough track, grades, and curves, and do not swing crosswise to the track in case of derailments.

The cab has a rigid underframe which is supported on two center pins located in the middle of the truck bolsters. Side-spring restraining plungers carry a portion of the cab weight on the inner truck bumpers. One center pin is provided with longitudinal motion to compensate for the changing center distances on curves. Normal design for a locomotive of this length and type would weigh considerably less than 125 tons. The additional ballast required by the starting conditions has been built into the structural members and provides a large ma gin of mechanical strength. A novel structural feature is the use of heavy end plates and rock guards which protect the motors, journal boxes, and steps from damage by loose rock and other track obstructions. Clearance below the rock guards is one inch less than the motor clearance.

To provide maximum visibility for the operator, cabs are of the steeple type, with sloping hoods at each end, and an elevated operating compartment in the center. In addition to the control compartment, there are five apparatus compartments, two at the ends for the battery, two adjacent equipment compartments, and a central resistor space under the operating deck.

Each of the two equipment compartments includes a blower for two traction motors and an air compressor, one for the air brakes and one for the car-dumping system. Electrical control apparatus for operation of the traction motors and auxiliaries is also housed in this space. Ventilating air is drawn in through air filters in the side walls and delivered to the traction motors through the hollow center bearings.

The control station is so located that the operator has full vision in all directions and by means of mirrors can see the blind side of the train. A double-shoe pantograph trolley is mounted on the roof of the operating compartment.

Performance

Under present operating conditions, a typical round-trip run between loading benches and the crusher is nine miles, with 470 feet change in elevation and

Figure 3. Electric locomotive spotting ore cars for loading at a bench shovel

Figure 4. Locomotive and train unloading waste

switchbacks involving four stops and reversals in each direction. The maximum round-trip run is 15 miles, with 770 feet change in elevation and several additional switchbacks. Numerous four per cent grades averaging 1,300 feet in length on switchbacks are with the load, which means that upgrade operation with the empty train is an important factor in determining locomotive capacity and schedule speeds.

The average round trip from bench to crusher requires about one hour, to which must be added a 1- to $1^1/_2$-hour loading period on the bench. Under ideal scheduling of operation, nine round trips will move 7,000 to 8,000 tons of ore in 24 hours.

Train lengths are adapted to the length of tail tracks at the switchbacks. Normally, trains are made up of nine 45-ton dump cars, each of which will hold 90 to 100 tons of ore, making a trailing load of 405 tons upgrade, and 1,200–1,300 tons downgrade. Safe downgrade speeds with full load are limited by curves and track conditions to from 12 to 18 miles per hour. Return speeds with empties are from 15 to 25 miles per hour, depending on the grade.

Speed and tractive-effort characteristics of the locomotive are shown in curve data form by Figure 6.

Motor Control

Because of the great variety of starting and running conditions, the three-speed system of motor control is used, involving series, series-parallel, and parallel connections for the four motors. The one-quarter and one-half speed connections are particularly useful in battery operation where economy of ampere-hours is important. Spotting of cars at the shovels and crusher also makes use of the low-speed notches.

There are a total of 22 starting notches, an ample number for starting a loaded train on grades and curves, without wheel slippage. Sand is used when rail conditions are abnormal. All motor combinations and resistor switching are managed with remotely controlled electropneumatic switches. The motors are also switched from line to battery power with an electropneumatic transfer switch. The controls for all motor and auxiliary operations are centrally located so that the operator has full charge of the entire locomotive without moving from the control platform.

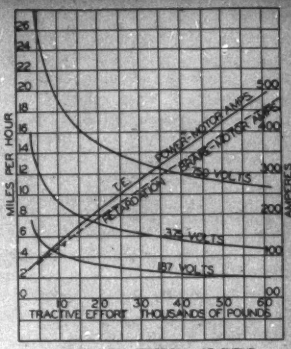
Figure 7 shows the distribution of the starting notches in terms of speed and load, and also the dynamic-braking notches which control retardation. Maximum current for acceleration can be held at 500 amperes per motor, and for braking 400 amperes per motor. Motor currents are indicated on cab ammeters at all times.

In the interest of simplicity and economy of space, the traction motor switching and resistor equipment are arranged for the double purpose of starting and dynamic braking. The additional equipment necessary for braking is thus held to a minimum.

Figures 8, 9, 10, and 11 illustrate the switching circuit combinations used for series, series-parallel, parallel, and dynamic braking.

As the master controller is moved from the 8th to the 9th, and from the 15th to the 16th notches, the motors are reconnected in the different combinations, resulting in higher voltage per motor and higher speed. The process of reconnecting the motors is known as transition. In the ninth notch, the motors of each truck are in series but the two trucks are now in parallel, giving one-half voltage to each motor and its series resistance. During the interim between the eighth and ninth notches, the motors of the number 2 truck are by-passed, giving a momentary loss of tractive effort. This is known as shunting transition.

Between the 15th and 16th notches, the motors in the two trucks are reconnected in parallel, giving full voltage per motor circuit. The change in this case is made by the bridge method wherein the transition is set up by paralleling the two motor circuits without interrupting the flow of current in either motor and, consequently, without loss of tractive effort.



LOCOMOTIVE PERFORMANCE CURVE

Figure 6. Locomotive performance and tractive-effort curve

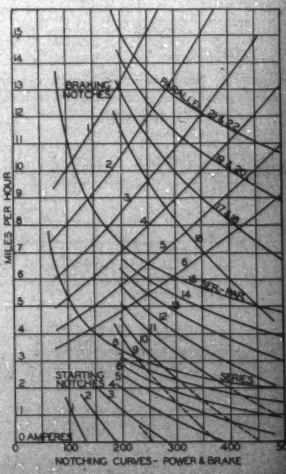


Figure 7. Power and brake-notching curves showing uniformity of current regulation

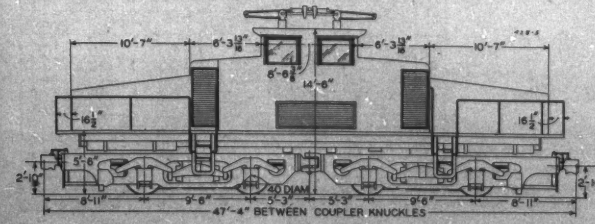


Figure 5. Side view and general dimensions of 125-ton electric locomotive

Obviously, the control of braking speeds with loaded trains on four per cent downgrades is an important feature of safe operation. Three braking systems are provided, the standard automatic air brake, a separate straight air nonautomatic train brake, and the dynamic brake.

The total braking effort necessary to hold a loaded train on four per cent grade is approximately 100,000 pounds which, if developed entirely by the brake shoes, would result in overheating and rapid wear of shoes and wheels, with frequent replacements and excess maintenance.

The dynamic brake, which is a generating action developed by the traction motors, is designed to supply approximately one half of the total retardation needed, or about 50,000 pounds. This relief of brake-shoe duty more than doubles the life of brake shoes, reduces the frequency of flat wheels, and provides an important safety factor in the handling of trains.

Series traction motors can be made to act as generators, and, when so doing, their torque is reversed, and they produce a braking action. This action, known as dynamic braking, is used to supplement the air braking to hold trains at constant speed on downgrades. The electrical output of the generators is absorbed by resistors.

If a series motor is driven from some mechanical source of power (as a locomotive axle) and a resistor is connected across its terminals, it will not build up to act as a generator because of improper direction of current in the series field. However, by using a pair of motors and connecting the resistor from a point between the armature and field of one motor to a corresponding point of the other motor, as shown by the circuit through the *BR* switch on the main schematic, the armature of one motor feeds the field of the other, and braking is obtained.

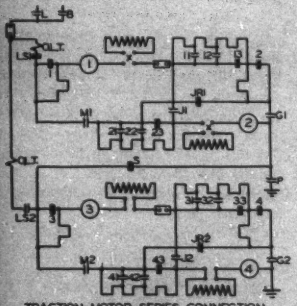
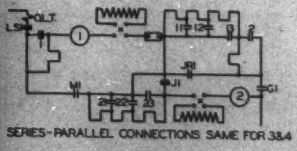


Figure 8. Motor-control schematic diagram showing series connection for slow-speed operation



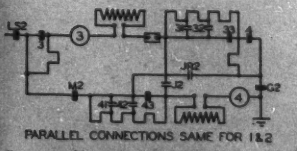


Figure 9. Schematic diagram for series-parallel and parallel connections

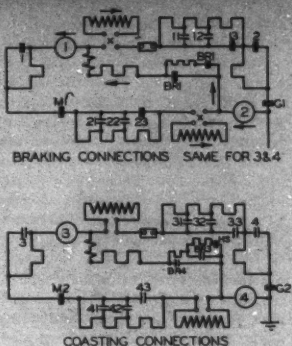


Figure 10. Schematic diagram of coasting and dynamic-braking connections

Each pair of motors, therefore, acts as a dynamic-braking system feeding its output into the resistor through the *BR* switches. Advance of the braking control varies the amount of resistance in series with each motor and hence the speed at which full dynamic-braking effect is obtained.

A resistor is connected across the *BR* 3 switch and is brought in circuit by the *HS* contactor, which is closed whenever the controller is in the "off" position. Its purpose is to set up a high-resistance braking circuit during coasting. The amount of braking effort produced by this circuit is negligible, but the current flowing in the resistance serves to provide a voltage for actuating the overspeed relay. At speeds above approximately 18 miles per hour, the voltage across the resistance is sufficient to cause the relay to lift, and this prevents the establishment of the full braking circuits. It is, therefore, impossible to obtain dynamic braking at excessive speeds, which would generate abnormally high voltages.

The energy generated by retardation must be dissipated as heat in the resistors. This is also true of the starting losses. In the service described, all of the resistor load periods are of short duration, making an ideal application for grid resistors of large thermal capacity, with natural ventilation. A small amount of air is diverted from the motor blower system to supplement ventilation of the resistors and to continue the cooling process while the locomotive is standing.

To get the maximum benefits from the dynamic system in holding a constant speed on heavy grades, there must be facilities for building the dynamic retardation up to a predetermined amount and then supplementing this with suffi-

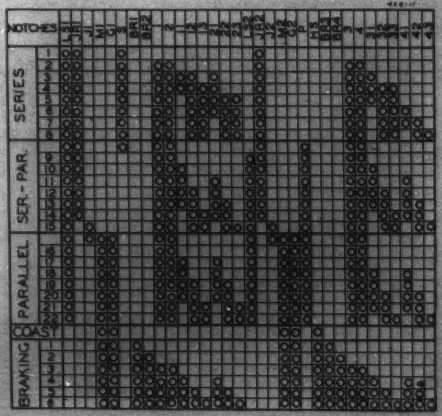


Figure 11. Sequence of switching applying to diagrams shown in Figures 8, 9, and 10

Figure 12. General view of a 750-volt 375-horsepower traction motor

roller-type armature bearings and oil and waste axle bearings. Labyrinths on the armature shaft and housing retain the grease for the roller bearings, so that greasing is needed only at infrequent intervals. The air intake for forced ventilation is cast into the frame at the rear and obtains air from a vertical opening in the truck bolster.

The inherent inductance of the motor is sufficient to smooth out ripples in the commutator. Field coils are seated between machined pads in the frame and spring washers under the pole tip. Coils are fitted tightly on the poles.

Commutating characteristics are such as to withstand the over-voltages encountered in dynamic-braking service and hold the volts per bar on the commutator within conservative limits. Armatures are dynamically balanced both before and after winding.

Figure 13. Operator's station, showing the arrangement of control, brake, and auxiliary levers

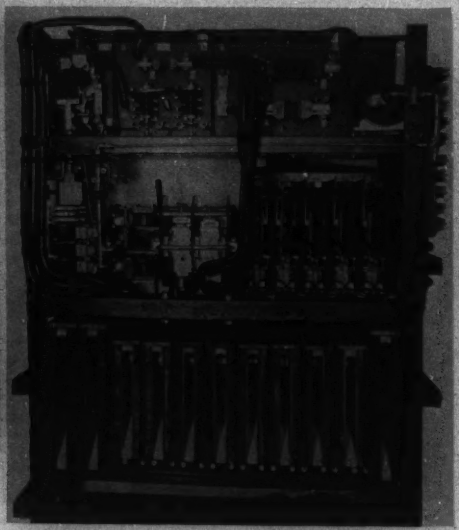


Figure 14 (right). Pre-assembled panel of motor-control apparatus

cient air braking to suit the load, grade, and the desired speed. In order to simplify the procedure of blending the two brakes, the dynamic load is regulated by series resistors to a constant value. Current-limit relays control the closing and opening of resistor switches to hold the braking effort between narrow limits over a speed range between 18 and 8 miles per hour. After the initial application, this regulation is automatic, leaving the operator free to give full attention to the manual graduation of the straight air train brake as needed to hold the desired speed.

Motors

Four 750-volt 340-horsepower axle-mounted traction motors drive the four axles through single-reduction spur gearing. Mechanical and electrical design features are especially suited to the type of service encountered in mine haulage.

A general view of the traction motor appears in Figure 12, which shows the frame as a heavy steel casting, with current supply. In addition, laminated commutating poles are used to reduce sparking at the commutator with sudden changes of current due to interruption and reapplication of power.

Armature and field coils are finished with class-*B* insulation, and the armature coils are heated and pressed before installation. After being connected, they are banded while hot, wedged with Micarta, and rebanded with nonmagnetic banding wire. These features reduce operating losses, improve the continuous rating, and reduce sparking volts at

Similar operating margins have been incorporated in the design of the blower and compressor motors. Each blower motor is rated ten horsepower at 400 volts and 2,100 rpm. The two are connected permanently in series, to take advantage of the resulting low-voltage commutator design. Compressors use direct drive from 25-horsepower, 800-rpm motors which are wound for full

Figure 15. A typical 1,000-horsepower 125-ton Diesel-electric locomotive

voltage and very generously proportioned to withstand the frequent starting service.

Operating Equipment

In arranging the operator's cab, particular attention has been given to convenience and visibility needed for frequent reversals of train movement. Figure 13 shows the arrangement which has proved to be most satisfactory.

All normal starting and braking functions are controlled by means of conveniently located master control and brake handles as follows:

22-notch motor controller.
Reversing-control lever.
Motor cutout switch.
Dynamic-brake master controller.
Automatic air-brake valve.
Independent locomotive brake lever.
Straight air train-brake valve.
Disconnect switch for auxiliaries.
Miscellaneous auxiliary switches and push buttons.

Certain of the auxiliaries, such as lights and master-control supply are fed directly from the battery at all times. Other auxiliaries, such as blowers and compressors, are switched to line or battery by the main transfer switch which is thrown by the operator when passing to and from the trolley-wire sections.

For convenience in maintenance, as well as in original manufacture, the motor-control equipment has been mounted in preassembled racks, as shown in Figure 14. One of these assemblies is mounted in each of the two hood compartments, which are isolated completely from the operator's cab. All power-switching equipment is remotely controlled and is of the well-known electropneumatic type, particularly adapted to heavy duty. An important factor in service reliability is the use of 1,500-volt rated insulation for power apparatus.

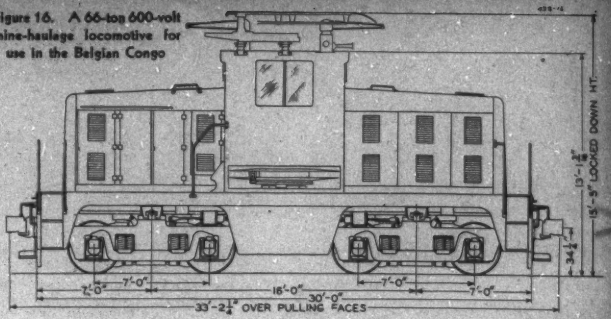


Figure 16. A 66-ton 600-volt mine-haulage locomotive for use in the Belgian Congo

In constructing the second lot of Morenci locomotives, it has been possible to incorporate numerous details of arrangement for operating and maintenance convenience, based on experience in handling the original installation. The final design is, therefore, adapted to the operating conditions on this particular property and also establishes standards which can be applied universally wherever large quantities of material are to be handled. That these aims have been realized, is indicated by the high degree of locomotive availability which is being maintained at Morenci Mine.

Other Modern Haulage Locomotives

Figure 15 illustrates one of the 125-ton Diesel-electric locomotives used in waste haulage and for general duty at Morenci Mine. With skillful dispatching, it is practicable to make economical use of both types of motive power in the varied phases of haulage service.

Stripping operations at present require the removal of approximately equal amounts of ore and waste. The Diesel-electric locomotives of 125 tons are used for a portion of the operation on the long dump tracks, which have light grades and no overhead wire. Line construction is being extended, with the addition of substation capacity, all pointing to the further general use of the electric locomotives.

The electric locomotive illustrated in Figure 16 is one of five 66-ton 42-inch gauge 600-volt units now under construction for use in open-pit copper mining in the Belgian Congo. The general characteristics are quite similar to those of the Morenci locomotives, with the exception that, instead of a storage battery for bench operation, a cable real and side-arm collectors are to be used. Short benches, and other differences in the mine layout indicate that a battery is not essential to satisfactory performance.

Maximum grades on this property are two per cent against the load. The empty train amounts to a trailing load of 220 tons, and the loaded train is 440 tons. These locomotives will handle all of the ore and waste haulage and will be subject to diversified grade conditions.

A New Electric Hoist Drive for Cranes

M. A. WHITING
ASSOCIATE AIEE

A NEW system of electric hoist drive has been developed, and its success has been demonstrated in practical use. For the types of hoist for which it is particularly intended this system provides a closer approach to the ideal characteristics than has previously been available. Although the system is not intended for use in all of the important types of hoist, it is expected that further experience and additional study of details and refinements will broaden its field of application beyond that which has, to date, been established in practice.

The Ideal Characteristics

Among the several hoisting applications for which the new system is believed to be suitable, the high-grade heavy-duty indoor cranes in steel mills and heavy machine shops may be considered typical. A study of the requirements indicates that the ideal characteristics for a crane of this type and of certain other types are principally as follows:

1. The same manipulation of the controller to any position in the lowering direction should cause the motor either to deliver power for lowering an empty hook or to absorb power for the proper lowering of a load, whichever is required by the conditions at that moment.

2. Maximum hoisting speed at empty hook should be a definite value, approximately twice the speed at rated load.

3. At the full-speed hoisting position of the controller the stalled torque should be limited to a reasonable overload value.

4. At the first-speed hoisting position the speed-torque curve should be relatively flat, having a very low speed at empty hook but a substantial stalled torque.

5. The maximum lowering speed at empty hook should be a definite selected value, between 160 per cent and twice rated hoisting speed.

6. Maximum speed of lowering rated load should be substantially less than at empty hook, and maximum speed of lowering maximum load should be less than that of lowering rated load.

7. The minimum lowering speeds, that is, the speeds at the first lowering-speed position of the controller should be nearly alike, irrespective of load. If readily attainable, it is preferable that this lowering speed be *less* at heavy loads than at partial loads or empty hook.

8. The electric equipment must have in the lowering direction a substantial margin, so that, when the maximum load which can be lifted is handled, the torque capacity available in the lowering direction is ample to maintain dependable control of the load under the most adverse conditions.

9. A safe and reasonably smooth retardation and stop must occur automatically in the event of failure of incoming power and other emergencies.

10. The regulating means by which the fifth, sixth, and seventh requirements are met must *not* be capable of stalling a load which is being lowered, however great that load may be, at any lowering position of the controller.

11. The electric equipment should be self-protective against abuse, either of itself or of the mechanical equipment, under the condition of rapid and unrestrained movement of the controller handle.

12. It is usually important that the holding brake be so controlled automatically that in regular service it is not required to supply any large part of the retardation effort.

The reasons for some of the items in this list of ideal requirement are probably evident. The reasons for some of the other items have been explained by J. A. Jackson.[1]

Characteristics of Previous Systems

The most highly developed crane-hoist system using an a-c motor consists of a conventional wound-rotor induction motor and secondary resistance control with the addition of d-c dynamic braking in the lowering direction. The d-c dynamic braking is obtained by exciting the motor stator with direct current and absorbing in a controlled resistor the power regenerated by the rotor when lowering a load. This system has proved very useful, particularly in shipyard cranes. Figure 1 shows typical speed curves at the various controller positions plotted against load on the hook, at an assumed mechanical efficiency of 87 per cent. Certain additional speed-load characteristics, not shown in Figure 1, are provided solely as automatic transition points for acceleration and retardation. The examination of Figure 1 shows that this system fulfills some of the ideal requirements stated in the introduction but departs considerably from this ideal in certain other respects.

For use with d-c power, the most highly developed crane-hoist-motor system commonly used is one in which the hoist motor is built as a series motor and is operated as a series motor in the hoisting direction. In the lowering direction a resistor of substantial capacity is connected to furnish a component of separate excitation to the series-wound field and to provide a dynamic-braking path for absorbing current regenerated by the armature when a load is being lowered. Several manufacturers build equipments of this type which are essentially similar but differ in some details, and whose characteristics are similar, with minor differences. This system has been in general and successful use for approximately 30 years and is a radical improvement over earlier practice. A typical set of speed-load characteristics is shown by Figure 2, which is a combination of Figures 5 and 6 of Jackson's paper.[1] A study of this figure shows that it meets or approximates some of the ideal characteristics set forth in the introduction but departs widely from this ideal in certain other respects.

That form of the Ward-Leonard system which uses a three-field "shovel-type" generator[2,3] has occasionally been proposed for the type of hoist here considered. Although this has been the standard system for shovels and is an

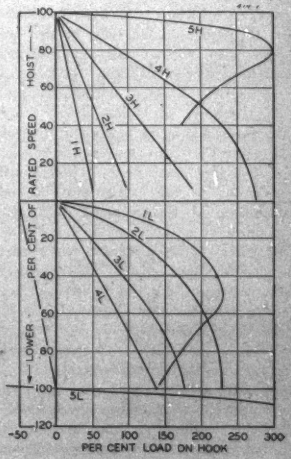


Figure 1. Characteristics of a-c crane hoist motor with d-c dynamic braking

Paper 44-19, recommended by the AIEE committee on industrial power applications for presentation at the AIEE winter technical meeting, New York, N. Y., January 24-28, 1944. Manuscript submitted November 10, 1943; made available for printing November 30, 1943.

M. A. Whiting is in the industrial engineering division, General Electric Company, Schenectady, N. Y.

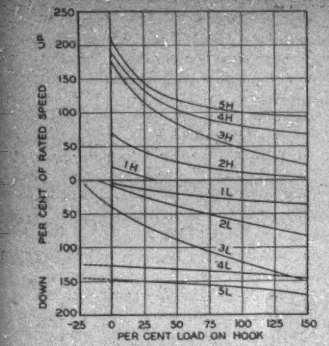


Figure 2. Characteristics of d-c series crane hoist motor with dynamic braking

excellent choice for certain other applications, its speed-torque curves differ widely from most of the ideal characteristics here considered.

The New System

The ideal characteristics for the applications under consideration have been approximated closely by the development of a radical improvement of the Ward-Leonard system, the principal feature of which is the addition of an exciter of unusual design embodying a cross-flux principle. By this means, a characteristic is obtained in which the voltage of this cross-flux exciter is responsive in a unique manner to the variations of magnitude and polarity of the current in the "loop" circuit, that is, the local circuit comprised by the armatures of the generator and hoist motor. At zero "loop" current the voltage of this exciter is at its maximum. At substantial increases of "loop" current, *irrespective of polarity*, the voltage of this exciter decreases, and at the maximum overload values of the "loop" current the voltage closely approaches zero. The voltage generated by this exciter provides the excitation of the generator field and modifies the excitation of the motor field. By means of the generator and motor-excitation characteristics thus provided, characteristics of speed versus load are obtained of the kind illustrated later in the paper (Figures 6 to 9).

The 9th and 12th requirements listed in the foregoing for the ideal crane hoist are met respectively by a simplified arrangement of an emergency dynamic-braking resistor in the hoist-motor armature circuit and by an improvement in the control details of the magnet brake. These two features are not dependent upon the cross-flux-exciter principle. They were, however, developed as contributions to the same project, namely, the attempt to achieve the almost perfect crane-hoist drive. Because of lack of space, these features are not described.

Construction of the Exciter

Figure 3 illustrates diagrammatically the principles of construction of the cross-flux exciter in its basic form. Although multipolar machines are possible, the exciters built to date are bipolar, by which is meant that the armature-winding and commutator connections are those of a normal bipolar machine. Four pole pieces are provided. In Figure 3 the two upper pole pieces constitute one "pole" insofar as relates to the generation of the output voltage. The two lower pole pieces constitute the other "pole." For reasons which will appear, a degree of artificial saturation is introduced in the pole pieces, for example, by notches in the sides of the pole pieces as indicated in Figure 3. In one design which has been used, all pole pieces are duplicate (ordinary manufacturing variations being entirely acceptable). In another design which has also been used, the diametrically opposite pole pieces $P1$ are duplicates, each having a high degree of artificial saturation; the diametrically opposite pole pieces $P2$ are duplicates but have a much less degree of artificial saturation. For the general explanation, let all pole pieces and their respective air gaps be considered duplicate.

Each pole piece carries a shunt main-field winding separately excited from the constant-voltage main-excitation bus, also a cross-field winding consisting of a few turns of heavy conductor connected in series in the "loop" circuit, that is, in the main armature circuit of the Ward-Leonard system. Corresponding windings ordinarily have equal numbers of turns upon all pole pieces. The polarity axis of the separately excited main field is shown by arrow m–m in Figure 3. Stated in another way, when the sole excitation is by this main field the two upper pole pieces are of like polarity, for example "north," and the two lower pole pieces are of like polarity, "south." The polarity axis of the heavy cross field is in quadrature to that of the main field, that is to say, if the sole excitation were that of the cross field, the two right-hand pole pieces would be of the same polarity, for example "north" at the normal direction of "loop" current, and the two left-hand pole pieces correspondingly would be of "south" polarity. For the normal direction of "loop" current, the polarity axis of the cross field is shown by arrow C–C. As a result of this arrangement of coil polarities, at the normal direction of "loop" current, the respective field windings are of additive effect upon both pole pieces $P1$ but are opposed upon both pole pieces $P2$, as indicated by the small arrows located alongside the respective coils in Figure 3. The respective fluxes, although merged in parts of the magnet frame and armature core, are separate in the pole pieces, air gaps, and armature teeth, in which almost all of the reluctance occurs; hence for all practical purposes it is substantially correct to consider the machine as having two independently saturable flux paths, one along line $P1$–$P1$, and the other along line $P2$–$P2$.

To avoid a possible misunderstanding, it should be noted that in Figure 3 the positions of the brushes as shown are diagrammatic only and represent the positions of the armature slot conductors at which they undergo commutation.

Commutation does not present any

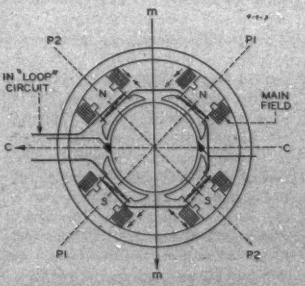


Figure 3. Diagrammatic representation of construction of cross-flux exciter

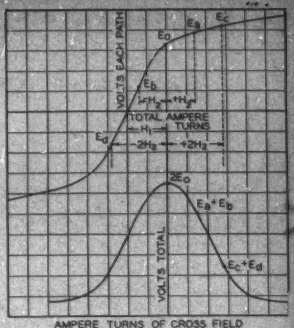


Figure 4. Theoretical characteristic of cross-flux exciter

greater problem than in an ordinary machine. Commutating poles are provided in accordance with usual practice. The commutation and characteristics are not sensitive to brush position, brush fit, or ordinary manufacturing variations.

Characteristics of the Exciter

In the circuit arrangement in which this exciter is used in the system, armature reaction and armature IR drop of the exciter tend, if not offset, to be of more than negligible effect, but they can be compensated sufficiently to make them almost negligible; consequently the explanation of the operation of the cross-flux exciter can be based upon a study of the no-load saturation curves of the respective flux paths. The upper part of Figure 4 represents the no-load saturation curve, not of the entire machine but of each of the two duplicate and practically independent flux paths, $P1$ and $P2$, respectively.

$H1$ represents the selected field strength of the separately excited main-field winding which remains substantially constant throughout. When the current in the cross field is zero, each flux path of the exciter causes the generation of a voltage E_a, and the total voltage generated is $2E_a$ plotted in the lower part of Figure 4 at zero cross-field ampere turns. Now assume a cross-field strength of $H2$. In flux path $P1$ the value of $H2$ is additive to $H1$, hence the voltage generated in this flux path is now E_a. In flux path $P2$ the value of $H2$ is subtractive from $H1$; hence the voltage generated in this flux path is now E_b. The total voltage generated is E_a+E_b, as plotted in the lower part of Figure 4. Since saturation increases beyond point E_a and decreases below E_a, voltage E_a+E_b is substantially less than $2E_a$. At a cross-field strength of $2H2$ the further increment of voltage generated in path $P1$ is very small, but the decrement of voltage generated in path $P2$ is large—in fact the voltage of path $P2$ reverses. The corresponding total voltage E_c+E_d accordingly is much reduced. When the two magnetic circuits are duplicate, and when the numbers of turns of the respective windings are equal upon all pole pieces, the negative voltage generated by path $P2$ cannot become quite so great as the voltage generated by path $P1$; hence the total voltage of the exciter never reaches zero. When the polarity of the cross-field current is opposite to the foregoing, path $P2$ behaves as did path $P1$ in the foregoing and conversely. Hence the characteristic of voltage generated versus cross-field (that is "loop" circuit) current tends to repeat symmetrically about the left-hand side of the vertical axis in the lower part of Figure 4. If compensation for armature reaction is not provided, this characteristic shows a departure from symmetry about the two sides of the vertical axis. The dissymmetry caused by armature reaction may or may not be practically disadvantageous, according to the specific design and application. To date, a design of exciter having closely symmetrical characteristics about the vertical axis has not been built. In the first design the armature reaction was not compensated. In a later design of a larger exciter the armature reaction was compensated, but a dissymmetry of characteristics was purposely introduced by means of unlike proportions of the respective flux paths.

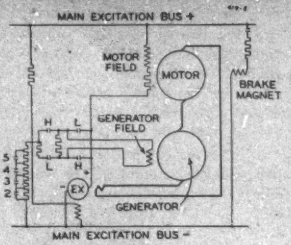


Figure 5. Elementary diagram—circuit arrangement of Ward-Leonard system using cross-flux exciter

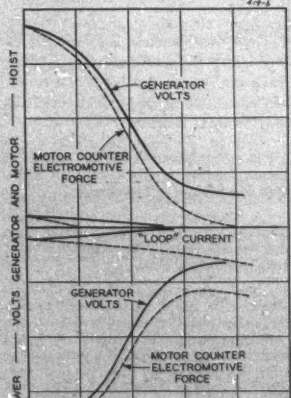


Figure 6. Theoretical characteristics—generator voltage and motor counter electromotive force of system of Figure 5

If a moderately greater value of separately excited field is held, represented by a higher value of H_1 in Figure 4, a voltage characteristic is obtained of similar shape having higher voltages throughout, and conversely for a moderately smaller value of separately excited field.

If the exciter of Figures 3 and 4 were only slightly saturated in each of its duplicate flux paths at the maximum cross-field current, its minimum output voltage (although substantially less than maximum) would not be so low as desired; hence a high degree of saturation is provided. This is done most suitably by providing a restricted section in each pole piece, for example by notches which are deep and also relatively long radially.

For reasons which will appear in the explanation of the system as a whole, it is usually important to offset or minimize the effect of IR drop of the exciter armature. Although not strictly necessary, it is usually advantageous to compensate the exciter for its armature reaction. By itself compounding may be provided by turns about each pole piece connected in series with the exciter armature, having polarities coinciding with that of main axis m–m. Perfect compensation for armature reaction tends to require a winding distributed over the pole arcs. Practically, however, a concentrated compensation provides all the benefit which is important. Such compensation can be provided by turns about each pole piece connected in series with the exciter armature, having polarities in line with the cross axis C–C. It might seem that for both of these improvements two field windings must be added to those of Figure 3. Actually only one added winding is required. Upon two pole pieces the polarities of the individual compounding and compensating windings would be alike, hence only one winding per pole piece is added having the sum of the turns individually required. Upon the other two pole pieces the polarities of the individual compounding and compensating windings would be opposed; hence only one winding per pole piece is added having the polarity and number of turns corresponding to the difference of the individual requirements.

Design and Arrangement of System

The generator is of normal design. Its main field is wound with the maximum practicable cross section of copper in order to provide the desired high no-load voltage with the least oversize of generator. Such a field winding provides a generator time constant which, in combination with

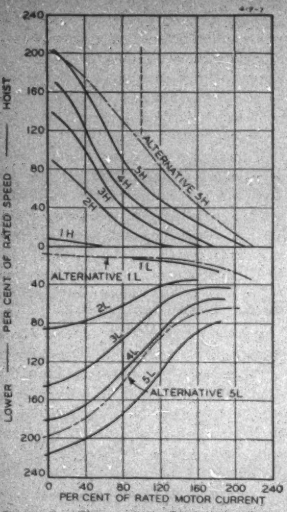


Figure 7. Characteristics from tests of developmental sample equipment

the circuit arrangement and cross-flux-exciter characteristics, limits the peak currents to values which are suitable for the electric equipment and the hoist system.

The generator, cross-flux exciter, and an ordinary constant-voltage exciter are driven by an induction motor, or if preferred for a sufficient reason by a synchronous motor or a d-c motor. An engine drive tends to be an improper choice, since the engine is unable to reconvert the energy regenerated by a descending load and hence is unable to restrain the speed of a descending load.

The hoist motor has a nonstandard main-field winding for a variable separate excitation but in other respects is of the type which is standard for high-class crane-hoist installations.

If it were intended to use the cross-flux exciter solely to furnish a generator excitation of the desired characteristics, it would be appropriate to consider an arrangement which connected the generator field directly to the armature of the cross-flux exciter, whereupon the hoist could be reversed and controlled by reversing and controlling the strength of the separately excited main field of this exciter. However, another important function of the cross-flux exciter is to provide an advantageous variation of the hoist-motor excitation. In order that one cross-flux exciter shall serve both of these purposes (by virtue of the unusual circuit arrangement used), it is necessary that the main-field excitation of this exciter be maintained nonreversible and at a substantial value which is not far from constant. Accordingly, a conventional reversing control is provided between the exciter armature and the generator field, as indicated in the elementary diagram of Figure 5.

In order to provide the desired variation of the hoist-motor field, the cross-flux exciter is designed for a maximum voltage substantially less than that of the constant-voltage main-excitation bus. One terminal of the cross-flux exciter, negative as shown in Figure 5, is connected permanently to the main-excitation bus terminal of like (that is negative) polarity. Thus between the positive terminals of these two sources of excitation a variable voltage is available which is the *difference* of the two voltages. The hoist-motor field is connected permanently between these two terminals. The excitation voltage thus made available may be visualized by referring to Figure 4 and considering the ordinate between the lower and the upper base lines as the main-excitation bus voltage. Thereupon the height of ordinate from the curve "volts total" upward to the upper base line represents the voltage applied to the hoist-motor field. Thus the hoist-motor field is weakest when the "loop" current is substantially zero, which occurs when the empty hook is being hoisted and lowered and when the motor is at standstill at the "off" position of the controller. As the "loop" current increases, the decrease of the cross-flux-exciter voltage causes an increase in the motor-field strength. Normal field strength occurs at approximately rated armature current of the hoist motor. Typically the minimum field current is approximately 60 per cent of normal, and the maximum is approximately $1\frac{1}{2}$ normal.

This scheme of motor-field excitation provides three benefits:

1. Most important: an ample margin of torque stability is provided at all loads, both steady-state and transient.

2. A maximum speed of the empty hook is obtained which is moderately greater than that corresponding to the maximum no-load voltage of the generator.

3. Without any complication of contactors, relays, or the like in the motor-field circuit, the motor field continues strong at the "off" position of the controller during a retardation but is reduced to a value moderately less than normal while the hoist continues to stand at rest at the "off" position.

Because the cross-flux exciter is used for two purposes, its armature current is the *difference* of the generator-field and motor-field currents. Thus at zero "loop" current the exciter armature current is at its maximum value as output. At rated "loop" current the generator-field current and motor-field current are nearly equal; hence the exciter armature current is not far from zero. At maximum "loop" current, when the exciter voltage is low accordingly, most of the hoist-motor field current becomes input into the exciter which accordingly acts regeneratively. The uncorrected effect of armature *IR* drop would be to decrease the maximum effective voltage of the exciter by a more than negligible percentage, but also to increase the minimum voltage of the exciter by a large percentage over the desired low value. It is principally for these reasons that the exciter is compounded as has been mentioned.

Certain optional features were added in the developmental sample, and tests were made both with and without their use. It was decided that the modifications of characteristics provided by these additions were not of sufficient importance to justify their inclusion in typical equipments. For this reason and because of space limitations these features are not described.

Speed-Torque Characteristics

The characteristics of the system are determined principally by the manner in which the generator voltage varies, subject, however, to the modifying effect of the *IR* drop of the "loop" circuit and the additional modifying effect of the motor-field variation. When the generator field is excited and controlled as described, the characteristics of generator voltage and of motor counter electro-

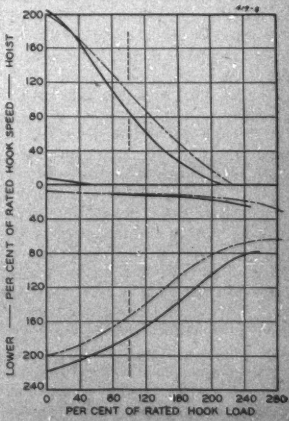


Figure 8. Calculated characteristics expressed as load on hook, from tests as in Figure 7

motive force with respect to "loop" current will resemble those of Figure 6, in which the curves of generator voltage represent not terminal voltage but voltage generated within the generator. In the upper right-hand quadrant, representing the hoisting of loads, the effect of "loop" circuit *IR* drop is subtractive from that of the generator voltage, but in the lower right-hand quadrant, representing the regenerative lowering of loads, this *IR* drop is additive. Hence the curves of motor counter electromotive force are not symmetrical in the hoisting and lowering direction, and upon any lowering position of the controller a stalled condition never occurs at any load, however large. If the hoist motor field were constant, the curves of motor counter electromotive force in Figure 6 would represent also the speed of the hoist motor. The effect of the variable motor field upon the speed-torque curves is to increase moderately the hoisting and lowering speeds at loads less than normal and to decrease slightly the speeds at overloads.

Figure 7 shows a set of speed-load characteristics from factory tests of the first equipment of this type. This equipment was a developmental sample for which only the cross-flux exciter, the control equipment, the brake magnet coil, and the hoist-motor-field winding were made for the purpose, the remainder

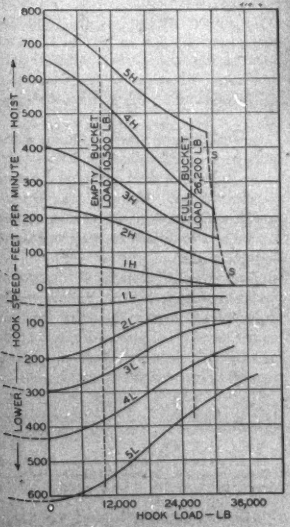


Figure 9. Characteristics of hoist of cantilever gantry crane, from tests of installation at Fontana Dam

of the equipment being borrowed from stock. The loading arrangement provided a "live" counter torque, produced electrically and adjustable over a wide range, which provided an authentic simulation of the various loads upon a hoisting hook. In accordance with typical crane practice five speed-control positions were provided in each direction. The characteristics shown by curves 1*H* to 5*H* and 1*L* to 5*L* drawn in solid lines were obtained when using the optional features mentioned. The simpler arrangement, omitting the optional features, provided the characteristics shown in dot–dash lines, labeled "alternative." The corresponding "alternative" characteristic for slowest hoisting was almost identical with the curve 1*H* shown. From the test data the characteristics of speed versus load on the hook were calculated for the slowest and fastest speeds, as shown in Figure 8. These characteristics were calculated on the basis of an assumed mechanical efficiency of 87 per cent. In the author's opinion the "alternative" characteristics shown by the dot–dash lines are to be preferred.

The characteristics shown in Figure 7 and Figure 8 are considered to be particularly suitable for cranes in steel plants and heavy machine shops, subject to the possible exception that the highest-speed lowering characteristics there shown may be faster than considered desirable. It is a simple matter to readjust so as to reduce the speeds of the fastest lowering characteristic and to redistribute the intermediate characteristics accordingly.

The speed-torque characteristics upon the *lowest-speed lowering position*, curves 1*L* in Figure 7 and Figure 8 show a moderately higher speed when lowering rated load or overloads than when lowering the empty hook; hence they do not meet completely the sixth item in the list of ideal characteristics. However, these speed characteristics are superior in this respect to the characteristics 1*L* in Figures 1 and 2, which represent approximately the best of the standard practice heretofore. By improvements in design it is not difficult to make a further improvement over the characteristic 1*L* of Figure 7 without detracting from any other characteristics. This has been proved in the larger equipment of later design whose characteristics are shown in Figure 9.

With the possible exception of an extraordinary combination of conditions a crane is never called upon to lower a hook load greater than that which it is capable of picking up and hoisting. However, in the factory tests of the developmental sample electric "live" loads were applied equivalent to hook loads substantially greater than any which could be lifted, as shown in Figure 8. At such excessive loads curves 1*L* show increases in speed. These, however, do not involve any tendency toward instability but are merely the result of increased *IR* drop of the "loop" circuit throughout the excessive overloads at which the generator voltage is at a nearly constant minimum. Throughout the entire overload range the hoist-motor excitation

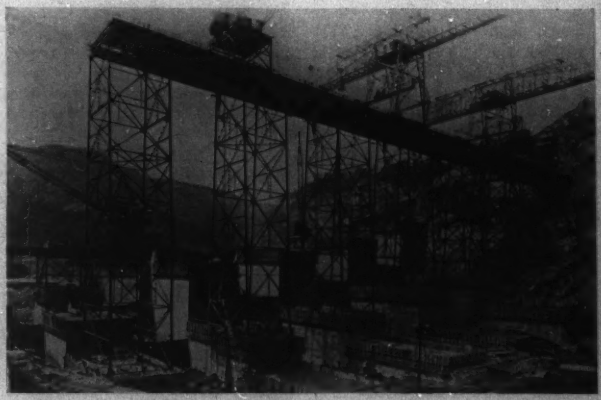


Figure 10. Fontana Dam construction trestle equipped with two cantilever gantry cranes for handling four-cubic-yard concreting buckets, provided with variable-voltage hoist control using Whiting cross-flux exciter system and variable-voltage rack motion with floating-flywheel exciter

increases until at maximum overloads including those which are impossible in practice the motor is highly saturated, and hence in a very stable condition.

A large installation comprises two high-speed high-lift cranes used in the construction of a dam on the Little Tennessee River at Fontana, N. C. Although these cranes are very different from a typical steel-mill or heavy factory crane, the ideal characteristics enumerated in the introduction are especially desirable in this application. Because of the unusual character of these cranes certain additional requirements are imposed upon the speed-load characteristics of the hoist. Accordingly the electric equipment for the hoist was designed in accordance with the same principles but with certain changes in proportions and one additional feature.

These cranes are of a type sometimes called "hammerhead" but more aptly named cantilever gantry cranes. They have a maximum lift of 295 feet and at the extreme outward travel of the rack (that is trolley) motion the overhang of the hoisting hook at the end of either cantilever is 128 feet beyond the supporting tower. The hoist drive of each crane has a rms rating of 187 horsepower. These cranes are used at times for roustabout work, but their principal duty is the "pouring" of concrete.

During the earlier part of the construction schedule the crane picks up a bucket of freshly mixed concrete from a railroad car running between the legs of the crane tower, hoists the bucket sufficiently to clear the side rails, racks out the bucket to the required distance, and lowers it to the upper surface of the "block" being poured. When the bucket has been dumped, it is hoisted, racked in, and landed on the car. When the dam reaches nearly its maximum height, the loaded bucket will be lifted from the car a maximum of about 50 feet, and, after racking out, dumping and racking in, the empty bucket will be lowered to land on the car.

The purchase specification required that the speed of hoisting the loaded bucket be a relatively high percentage of the speed of hoisting the empty bucket but required also protection against an excessive overturning moment. Although the loaded bucket at its maximum overhang is entirely incapable of overturning the crane, it is possible when the crane is engaged in roustabout work that a hoisting hitch may be taken about an excessively heavy piece or an immovable object. Under the latter circumstances it is imperative that the hoisting effort shall be self-limiting to a value substantially less than the overturning moment of the crane.

In order to meet these requirements and at the same time retain the various other desirable characteristics, a cross-flux exciter was designed in which the two flux paths were purposely dissimilar whereby a set of speed-load curves was obtained as shown in Figure 9 based upon tests of the installation. In order to limit the stalled torque of the hoist motor to a value only moderately greater than its value for hoisting the maximum load in regular service, a simple addition was devised which causes the characteristics of the cross-flux exciter to break abruptly from the normal characteristic for which it is adjusted and at higher values of "loop" current to provide the stalling characteristic shown in Figure 9 by the broken lines *S–S*.

In addition to its adaptation to the special requirements just mentioned, the characteristics of this equipment provide two improvements over those of the developmental sample. The first-speed hoisting characteristic, curve 1*H*, is flatter. The first-speed lowering characteristic, curve 1*L*, goes all the way in meeting the seventh item in the list of ideal characteristics ". . . that the lowering speed be *less* at heavy loads than at partial loads or empty hook."

Transient Characteristics

As was predicted when the system was first devised on paper, the superior steady-state characteristics and the means by which these characteristics are obtained contribute to the creation of favorable transient operating characteristics during the course of ordinary accelerations, retardations, and reversals, and during emergency stops. Because the maximum speed when lowering a heavy load is much less than when lowering a light load or the empty hook, the kinetic stored energy of the hoisting system is inherently reduced whenever increased hook loads are being lowered. Under these conditions the generator-field current is also much less than maximum; hence at a quick movement of the controller from full speed to the "off" position (or to a hoisting position) the initial rate of decay of generator field is much less than maximum. At the heavier loads the motor field is strong, and an increase of "loop" current for the retardation causes a further increase of motor-field current. From the combination of these phenomena it comes about that the retardation of heavy descending load requires a "loop" current only moderately greater than that of the speed from which the retardation is begun and only a little greater than that for retarding the empty hook from its maximum speed.

This combination of phenomena is similarly and equally beneficial with respect to the retardation and stop under emergency conditions such as failure of incoming power. It has been observed that when maximum load is being lowered at its maximum speed an emergency stop requires only slightly more current from the hoist motor than is required for the corresponding emergency stop of the empty hook and little more than for a normal retardation at the maximum rate.

Conclusion

The hoisting-machinery art includes many different types of equipment for widely different applications. Some of these types of hoist have relatively unexacting requirements which are met acceptably by various simple systems of electric drive. Several systems of electric-hoist drives have been developed, each of which has certain specialized modifications which are particularly advantageous for certain exacting applications but which are irrelevant or disadvantageous for certain other hoisting applications whose requirements are equally exacting but different. The electric system described in this paper is not to be considered as preferable or even applicable for every important type of hoist, but it is intended for use in several types of hoist in which, notwithstanding certain substantial differences of design and use, the speed-torque requirements are similar.

No installations have yet been made in large heavy-duty indoor cranes such as are typical of steel plants and heavy machine shops. However, the results first demonstrated by the developmental sample and confirmed in practice by the Fontana Dam installation indicate the suitability and advantages of the system for heavy-duty indoor cranes. It seems reasonable to expect that with further experience and additional study of details and refinements the field of application will be broadened further.

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Gear Ratio and Its Effect on Traction Motors

G. M. WOODS
MEMBER AIEE

Synopsis: The mechanical power delivered by the motors of electrically propelled vehicles is almost always transmitted through gears to axles. The few exceptions are some gearless electric locomotives designed many years ago. Although the top speeds of vehicles and locomotives have increased materially since the inception of electric drive, the very nature of the service requires high tractive efforts in starting from standstill and at low speeds. In the case of transit vehicles, frequent stops require operation at relatively low speeds a large percentage of the time.

The history of traction-motor design discloses a trend toward higher and higher motor speeds. These higher speeds have resulted in reduced motor weight and space requirements, which are two most important considerations in traction apparatus. In order to use motors of higher speed economically, greater gear reductions are required. As developments in gear design, gear materials, and heat treatments progressed, greater gear reductions became practicable, and the higher-speed motors came into general use. Modern double-reduction gear units and hypoid gears permit greater gear reductions and, hence, higher motor speeds than the single-reduction spur gears which were once employed in all traction applications.

The reductions in weight and size of traction motors are not only advantageous in themselves, but they permit features in vehicle construction which add to the comfort and convenience of passengers and to over-all economy of operation. This paper discusses some of the elementary considerations of gear design and includes a specific example of the effect of change in gear ratio on traction motors.

THE electric motor is extremely well adapted to high-speed operation. The higher the speed at which it can be operated, within limits, the lighter and more compact the motor. The wheel speeds of electrically propelled vehicles and locomotives are quite low by comparison, because they have to start from zero speed at frequent intervals, and even at top vehicle speeds the wheel speed is still too low for economical gearless motor design. As a result, practically all propulsion motors are geared to the axles, the gear reduction serving the usual two-fold purpose of reducing the speed and multiplying the torque. As improvements in gear materials, heat treatments, and designs have made greater reductions practicable, it has been possible to utilize economically motors of higher speed. Streetcar motors serve as a good example of this trend, because they were the earliest traction motors, and continued progress has been required to keep streetcars competitive with other forms of transportation.

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G. M. Woods is in the transportation department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Early Motor Designs

All early traction motors were supported at one side by bearings on the axle and on the other by a connection to the car or locomotive truck. The distance between the center of the pinion, mounted on the motor shaft and the center of the gear, mounted on the axle was fixed for each motor frame. This gear-center distance is SA in Figure 1A. This distance is divided into two parts, SB and BA, so selected that BA divided by SB gives the speed reduction desired. The two circles shown with A and S as centers are known as pitch circles of the gear and pinion, respectively. The gear teeth are laid out around these circles.

Let us assume that the gear-center distance of a particular motor was 14 inches and the diametral pitch of the gears three. The total number of teeth in gear and pinion was $3\times2\times14=84$. The values selected are typical of the gears used on 40- and 50-horsepower 500-volt streetcar motors 35 to 40 years ago. At that time a 15-tooth three-diametral-pitch pinion was the smallest in general use, because a smaller pinion did not have sufficient strength between the root of the tooth and the bore, or at the keyway, with the best material available at that time.

In the example selected there must be $84-15=69$ teeth in the gear. The diameter over the ends of the gear teeth was $(69+2)/3=23.67$ inches. With new wheels a clearance of four-inches between top of rail and bottom of gear case was considered essential to avoid hitting the gear case on obstructions in the street. The outside diameter of the gear case was approximately one inch greater than the diameter over the ends of the gear teeth to allow for clearance in the gear case and thickness of the gear case. Therefore, the diameter of the new wheel could not be less than $23.67+1+8=32.67$ inches, and 33-inch wheels were in common use. They were worn to a minimum diameter of 30 inches; thus, the clearance under the gear case was reduced by 1.5 inches. The limitations of pinion and gear design made gear reductions of 4.6:1 general and 33-inch wheels a standard for city cars.

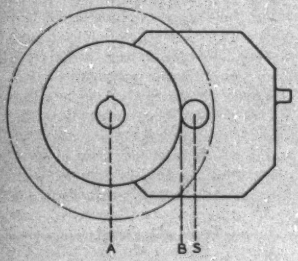
The streetcars of this period weighed 50,000 pounds and were propelled by four 40- or 50-horsepower 500-volt motors, depending to a great extent on the grade conditions of the city in which they were operated. The clearance between the top and the rail and the bottom of the motor frame, with 33-inch wheels, was also approximately four inches. The 40-horsepower motor weighed 2,800 pounds, complete with gear and gear case, and 2,400 pounds without gear and gear case. The maximum safe speed of the motor was 1,900 rpm, which resulted in peripheral speeds of 7,000 feet per minute of the armature and 5,100 feet per minute of the commutator.

There was not much change in motor speeds for a number of years, although progress was made along other lines. Motors with commutating poles became standard, and ratings were based on 600 volts with a resulting increase in horsepower of 20 per cent. Bearings and shafts were improved. Better gear materials were used, and heat treating became general. Progress was made in insulating materials. During this period the traction motor progressed from the state where normal life of pinions, bearings, windings, brushes, and commutators was short to where life of these parts was increased several times.

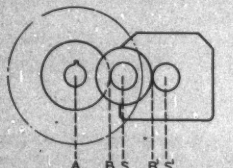
New Motor Designs and Low-Floor Cars

The year 1912 marked a traction-motor and streetcar development which radically changed the appearance of streetcars and the ease with which passengers could board and alight from them. The Pittsburgh Railways Company designed a car with 24-inch wheels and correspondingly low-car floors. The car seated 55 passengers, and its weight was only 34,000 pounds. Four 35-horsepower 600-volt motors were adequate for even the severe grade and traffic conditions of Pittsburgh.

The design of a motor for 24-inch wheels was an undertaking of considerable magnitude at that time. The motor developed was known as the Westinghouse type 328. It was self-ventilated by means of a fan on the armature shaft, and in the original design the coils were "bakelized." Gears of 3.5 diametral pitch were used, and the face of the gears was four inches instead of five inches, as used previously. The use of the $3^1/_2$-pitch gears made it possible to get the required reduction in the space available. Because of progress in gear construction, these gears proved entirely satisfactory. The clearance under the motor frame was $3^1/_4$ inches



A. Motor with single-reduction gears



B. Motor with double-reduction gears

Figure 1

and under the gear case three inches. This sacrifice of one-inch clearance meant that, for parallel street conditions, the wheels could not be worn to the same extent as on the older cars. Actually, the 24-inch wheels were later superseded as standard by 26-inch wheels, thus increasing clearances one inch.

The gear-center distance of the new motor was 10.43 inches, making a total of 73 teeth. A 15-tooth 3.5-pitch pinion was the minimum permissible. The maximum reduction-gear ratio was 58:15 or 3.87:1, but this gear reduction with 24-inch wheels is equivalent to a reduction of 5:32:1 with 33-inch wheels.

The maximum safe armature speed of the motor was 2,600 rpm. At this speed the peripheral speed of the armature was 6,800 feet per minute and of the commutator 5,800 feet per minute. While the maximum safe speed of the armature was raised 37 per cent, the peripheral speed of the armature was held essentially the same by reducing the diameter, and the peripheral speed of the commutator was increased only 14 per cent. The motor complete with gear and gear case weighed 1,680 pounds or a reduction of 40 per cent compared with the 50-horsepower 500-volt (60-horsepower 600 volts) motor used on the heavier cars. The total weight saving, due to the four lighter motors, was 4,480 pounds. The saving, due to using 24-inch instead of 33-inch wheels and the resulting lighter truck structure, was 4,000 pounds. Other weight economy was effected in the car body.

For the next 15 years street-railway motor design followed the trail blazed by this first motor suitable for low-floor cars. In a few years ventilated motors suitable for 26-inch wheels were available in 25-, 40-, and 50-horsepower sizes. A gear reduction of 5.7:1 was used on 25-horsepower motors, gears of $4^1/_4$ diametral pitch being employed. Again, there was a period of perfecting of details and consolidation of advances.

One of the latest axle-hung motors developed had a one-hour rating of 50 horsepower at 1,000 rpm. It weighed 1,940 pounds without gear and gear case and 2,185 pounds with gear and gear case. It had a gear reduction of 53:14 or 3.78:1 when gears of three diametral pitch were used. The maximum safe speed of armature was 3,000 rpm. The corresponding peripheral speed of the armature was 8,650 feet per minute and of the commutator 7,060. The car speed corresponding to 3,000 armature rpm was 61 miles per hour. While the peripheral speeds were raised at the maximum safe armature speed, the corresponding car speed was so high that it was rarely, if ever, reached in urban service.

Separate Gear Units

In 1927 a radical change in method of transmitting motor torque to the street-car axles was tried experimentally. Worm gears were used. The time-honored axle-hung motor, sleeve bearings, grease-lubricated spur gears and split gear case was a crude noisy arrangement by private automobile standards. It did function successfully. Two cars were constructed using worm-drive axles, including differential gears, which were an outgrowth of bus and truck axles. Oil-lubricated gears in a dirt-tight case were employed. The gears were silent. Gear ratios of 10:1 were available. The separation of the gear unit from the motor removed the restriction of gear center distance as a determining factor in gear ratio and allowed the most economical motor speed to be selected.

On the first experimental cars high-speed motors, developed primarily for gas-electric bus service, were applied. These motors were soon superseded by a high-speed railway motor specifically developed for the service. This motor rated 35 horsepower and had a maximum safe armature speed of 5,000 rpm. The maximum armature peripheral speed was 11,100 feet per minute, and the maximum commutator peripheral speed was 9,500 feet per minute. The motor weight was 570 pounds. Since the motors were entirely spring suspended, lighter-weight construction was more practicable than it was in former designs, where they were subjected directly to all the impacts of the wheels on rail irregularities. The worm-drive axles proved to be unsatisfactory in railway service, but they hastened the development of much-higher-speed motors than were previously used and other forms of gear drive which have proved satisfactory.

Table I. Comparison of Traction Motors

Horsepower	Volts	Gear Ratio	Wheel Diameter—Inches	Total** Reduction	Maximum Safe Speed—Rpm	Peripheral Speed Feet Per Minute		Bare Motor Weight—Pounds Per Horsepower	Miles Per Hour at Maximum Rpm	Clearance (Inches)	
						Armature	Commutator			Motor	Gear Case
40	500	4.6 : 1	33	0.0213	1,900	7,000	5,100	60.0	40	$4^1/_4$	4
50	600	4.6 : 1	33	0.0213	1,900	7,000	5,100	47.8	40	$4^1/_4$	4
35	600	3.87:1	24	0.0185	2,600	6,800	5,800	42.6	48	$3^1/_4$	3
50	600	3.78:1	26	0.0204	3,000	8,650	7,060	38.8	61	$3^3/_4$	$3^1/_2$
35	300/600	9:1	22*	0.0073	5,000	11,100	9,500	16.3	36.5	5	$4^1/_4$
55	300/600	7.17:1	25	0.0104	5,000	12,100	9,300	12.7	62	6	$4^1/_4$

* With *WN* double-reduction drive.

** Rpm × total reduction = miles per hour Total reduction = $\frac{\text{wheel diameter}}{336 \times \text{gear ratio}}$

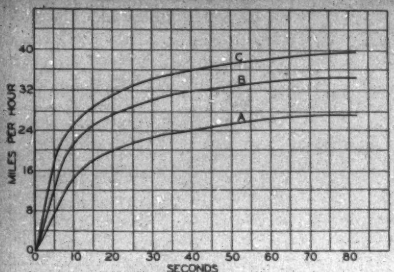


Figure 2. Speed–time curves

Car *A*. 48,000 pounds empty, 6,000 pounds passenger load, four 40-horsepower 500-volt motors, 69:15 gear ratio, 33 inches wheel diameter

Car *B*. 38,800 pounds empty, 6,000 pounds passenger load, four 50-horsepower 600-volt motors, 53:14 gear ratio, 26 inches wheel diameter

Car *C*. 33,000 pounds empty, 6,000 pounds passenger load, four 55-horsepower 600-volt motors, 7.17:1 gear ratio, 25 inches wheel diameter

The application of worm drive to streetcars was followed very quickly by the development of a double-reduction and a single-reduction self-contained gear unit which possessed most of the advantages of the worm drive. When the gear teeth were ground, the accuracy of tooth contact was improved. Antifriction bearings maintained gear-center distances accurately. As a result, the gear noise was reduced so greatly that the average passenger was not conscious of it. Also, gears of higher diametral pitch were used successfully. The double-reduction unit employed high-speed gears of $4^1/_2$ diametral pitch and the low-speed gears four. Phenomenally, long gear and bearing life was obtained. The spur gear units were more efficient than the worm drive.

The double-reduction drive permitted the use of wheels having a diameter of 22 inches with 4.5 inches clearance under the gear case. Figure 1B illustrates the double-reduction gear arrangement. The maximum gear reduction was 9:1, although most applications were made with less reduction in order to obtain the higher car speeds which were coming into general use. The single-reduction drive provided a maximum reduction of 7:1 and required 26-inch wheels to give $3^3/_4$ inches clearance between top of rail and bottom of gear unit.

Presidents' Conference Committee Car

Just at the time that these drives were proving their worth in service, the Electric Railways Presidents' Conference Committee was engaged in designing a completely new streetcar. New standards of performance in rates and smoothness of acceleration and braking, speed, passenger comfort, heating, ventilation, and lighting were established. Entirely new car body and car trucks, including rubber-cushioned wheels, were developed. A right-angle drive (motor shaft at right angles to axle) was selected, because it was better fitted to the truck design, was believed to be inherently quieter than the double-reduction spur gears, and was less expensive. The drive selected consisted of hypoid gears with 7.17:1 reduction. Antifriction bearings and oil lubrication were used. This drive embodied the advances of automotive-gearing design and has operated most successfully.

The new standards of performance required the design of a new motor having a one-hour rating of 55 horsepower. The four motors not only propel the car but do most of the braking dynamically. The dynamic braking is supplemented by electrically operated track brakes and air-operated brakes on the car wheels or electrically operated drum brakes on the armature shaft. The energy dissipated in the accelerating and braking resistors is used for heating the car during cold weather.

The new motor weighs 700 pounds and has a maximum safe speed of 5,000 rpm. At 5,000 rpm the peripheral speed of the armature is 12,100 feet per minute and of the commutator 9,300. The corresponding maximum car speed is 52 miles per hour. Wheels of 25-inch diameter are used. The clearance under the gear housing is $4^1/_4$ inches. The motors are completely spring-born, and, therefore, their height above the rail varies somewhat with passenger load. Normally, it is six inches.

For convenience of comparison Table I shows the principal characteristics of the various motors which have been discussed. They are typical of the streetcar motors used at various times in the past 40 years. Worthy of note are the increase in total reduction, the consistent increase in maximum safe speed, and in armature and commutator peripheral speeds. Although these changes did not accompany improvements in gearing step by step, they were in large measure the

Table II

Car	Schedule Speed (Miles Per Hour)	Kilowatt-Hours Per Car Mile
A	10.4	3.6
B	12.5	4.4
C	14.4	5.3

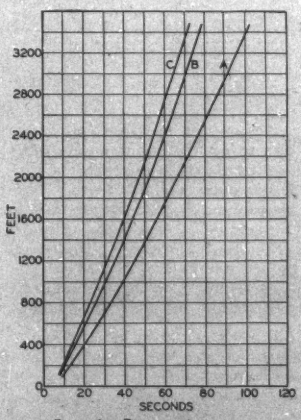


Figure 3. Distance–time curves

Cars *A*, *B*, and *C* as in Figure 2

Table III

Gear Ratio	Schedule Speed (Miles Per Hour)	Kilowatt-Hours Per Coach Mile	Root Mean Square Amperes
9.2:1	15.7	2.7	156
11.4:1	15.2	3.4	131

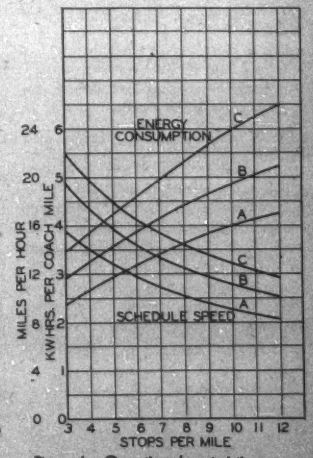


Figure 4. Operating-characteristic curves

Cars *A*, *B*, and *C* as in Figure 2

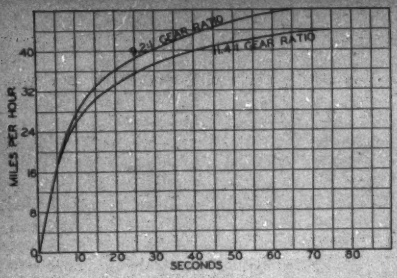


Figure 5. Speed-time curves
Trolley coach with 9.2:1 and 11.4:1 gear ratios

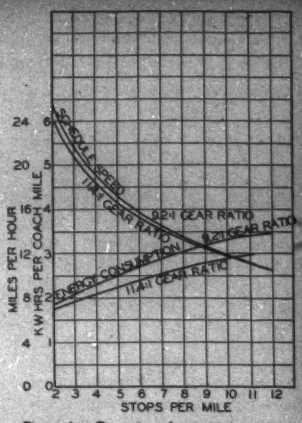


Figure 6. Operating-characteristic curves
Trolley coach with 9.2:1 and 11.4:1 gear ratios

result of gradual gear evolution. Cast iron and malleable iron were superseded by cast steel, forged steel, and alloy steels. The 14½-degree involute tooth form was superseded by 20 degrees involute, thus increasing strength. Long and short addendum pinions and gears were adopted with resulting greater pinion strength and more metal between root of tooth and pinion bore. Therefore, smaller pinions can be used. Water quenching, oil quenching, case hardening, and flame hardening were introduced.

Figure 2 shows the comparative speed attained in a given time by three types of cars. Car *A* is one typical of those in use 40 years ago. Car *B* represents the best type of car with axle-hung motors available in the late 1920's. Car *C* is the modern PCC car. To attain a speed of 25 miles per hour requires 48 seconds for car *A*, 16 seconds for car *B*, and 10 seconds for car *C*.

Figure 3 shows the distance covered by each car for various moving times. A distance of 1,000 feet is traversed in 39 seconds by car *A*, 31 seconds by car *B*, and 27.5 seconds by car *C*.

Figure 4 shows the schedule speed in miles per hour and the energy consumption in kilowatt-hours per car-mile for various stops per mile between 3 and 12. The comparison at eight stops per mile is shown in Table II.

It should be understood that these values are theoretical, and, that, in actual practice both schedule speeds and energy consumption are lower for all three cars than calculated. Although the energy consumption of car *C* is relatively high, it affords a superior service which requires more power. High-schedule speeds not only appeal to the patrons, but the wages of car operators per car-mile vary inversely, as schedule speed and operators' wages are the principal item of operating expense.

Trolley-Coach Performance

The trolley coach is selected as the means of illustrating the effect of gear ratio on traction-motor performance for a given set of conditions. Modern streetcars are standardized to such extent that the same gear ratio is used in all applications. Various gear ratios are applied on trolley coaches. Figure 5 shows the comparative speeds of a typical trolley coach with gear ratios of 9.2:1 and 11.4:1. Trolley-coach gear ratios are greater than streetcar ratios, because the rubber-tired wheels have an effective diameter of 40 to 43 inches instead of 25.

Figure 6 shows the schedule speed and energy consumption for a typical trolley coach with each gear ratio. Not only are schedule speed and energy consumption increased by decreased gear reduction, but also motor rms current is increased. At six stops per mile the comparison is as indicated in Table III. The percentage increase in schedule speed is small compared with the increase in energy consumption and rms current.

Conclusion

It is apparent that great progress has been made in the performance of vehicles on the street as the direct result of progress in motor and gear design. There has been equally great progress made in car design as a result of less space and weight required for motors. When wheel diameters are reduced from 33 inches to 25 inches, car floor height is reduced a corresponding amount. This results in one less step, which, in turn, means greater safety, less boarding and alighting time, shorter stops, and, hence, higher schedule speeds.

All are familiar with the outward changes in streetcars and trolley coaches. Unfortunately, too many examples of old street cars are in evidence for one to forget their outstanding characteristics. The more pleasing appearance, smoother and quieter operation, and better ventilation and heating in new streetcars are indirect results of progress in motor design.

Higher motor speeds brought with them improved commutator and armature construction and dynamic balancing. Better insulating materials, notably the general use of class-*B* instead of class-*A* insulation, and more effective ventilation, have made important contributions to reduced size and weight. Greater gear reduction has been essential to the economic application of these higher-speed motors.

References

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2. Modern Transportation Motors, H. W. Gouldthorpe. *Mass Transportation*, volume 36, March 1940, pages 64–6.

The Effect of Kilovar Supply on the Design of Systems for Load Growth

T. W. SCHROEDER
ASSOCIATE AIEE

J. W. BUTLER
MEMBER AIEE

N. H. MEYERS
ASSOCIATE AIEE

THE benefits that can be obtained by the use of shunt capacitors in electric power systems have been discussed many times in the technical literature. Their ability to improve voltage and power factor in the distribution areas, thereby reducing losses and postponing the need for additional circuit capacity by reducing loading on existing equipment, has been used many times where the economics have justified such use.

Again, other discussions have shown that the greatest use of a given total system investment may be obtained when the basic kilovar requirements are supplied near the load by either capacitors or condensers. It is the purpose of the present paper to combine these two major thoughts by investigating the place of the capacitor in providing for load growth on a specific system. This approach will give some indication of the economics and the benefits to be gained on an over-all system basis, which in the final analysis is the most logical view to take.

In many cases kilovar supply by capacitors, for a single purpose, such as voltage improvement, reduction in transformer, line or cable loading, may not be justified, as other means may permit a lower first cost (as will be shown), but when these effects are viewed jointly and evaluated on a system-wide basis, a different conclusion may result.

Basis of Analysis

To permit a study of the possibilities of capacitors as a stepping stone in system growth, a type of power system using modern design principles was assumed. Although a synthetic system, electrical details of the circuits were worked out from the residential customer entrance and commercial and industrial customer transformer secondary circuits back to the generating plant. This was called the present system. Then each portion of the system was redesigned to enable it to carry a load increase which would be obtained at some future time, the new load and system being designated as future. The kilowatt portion of the load increase viewed at the generating plants amounted to 67 per cent, although this percentage varied somewhat for each individual portion of the system. The necessary design changes made in the present system to derive the future system capable of carrying the increased loads, were made to each of the various parts in two ways:

1. By replacing present conductors, transformers, and regulators with larger ones, or adding to such equipment.

2. By supplying part of the future load kilovars by capacitors, thus reducing the extent to which other equipment had to be increased.

Estimated installed cost figures were applied to the two methods for economic comparison, and the future system was set up both ways on the network analyzer to permit a comparison of over-all operating performance.

In general, the various feeder circuits were designed in either case with the same amount of margin for a still further increase in load, or so-called slack.

Conclusions

It will be realized that the area, within the system in which the use of capacitors shows an economic gain, depends very greatly on the character of the system in question. Where the unit or small substation principle is applied making the low-voltage heavily loaded circuit runs comparatively short, the gains are less in the distribution areas by themselves. This principle of system design tends to shift the major benefits from the distribution to other parts of the system.

The type of system selected in this study employed the unit- or small-substation principle quite extensively, as will be discussed more in detail later; so this fact should be borne in mind in considering the following conclusions. These conclusions must, of necessity, apply rigorously only to the system studied, although certain generalizations will be apparent from them.

1. Exclusive of the increased generating-plant facilities to care for the future requirements (which were the same in either case), the use of capacitors resulted in an over-all saving of approximately $262,400 on a $2,500,000 investment, or about 10 per cent.

2. The total estimated cost of changing only the feeder circuits to accommodate the increased loads, either with or without capacitors, was about the same. In one type of feeder the cost of using capacitors would be greater than that of increasing the materials or adding feeder voltage regulators, and so forth, whereas in another the relative cost would favor the capacitor, and, in the aggregate, on the system studied the cost was about a standoff.

3. The greatest differential in cost of increasing the capacity of the feeder circuits favoring the capacitor method occurred in the residential-type feeders, where the improvement of the first-to-last customer voltage of the single-phase lateral circuits with capacitors precludes the need of adding conductors and reconnecting for three-phase, which must be done for voltage purposes, if capacitors are not used.

4. The greatest differential in cost favoring not using capacitors was on the 33-kv feeders supplying industrial power at 33 kv where strictly no change to the feeder was required to enable it to carry the future load. A large capacitor bank was added, however, at the end of each of these for the capacitor case, because this would be a logical location in this system for a kilovar source in such a program.

5. The total estimated cost of changing the substation and subtransmission facilities, if capacitors were used on the feeders, was $139,500 as compared with $383,700 if capacitors were not used.

6. The operating margin in the generating plants under future load with capacitors was increased by a reduction in system losses of 7,900 kw and 34,000 kilovars on a system-delivered peak load of 255,000 kw. The additional margins provided would allow the system to operate with one less hydrogenerating unit under emergency conditions, if steam and prime-mover capacity were available. This is seen clearly in Figure 11.

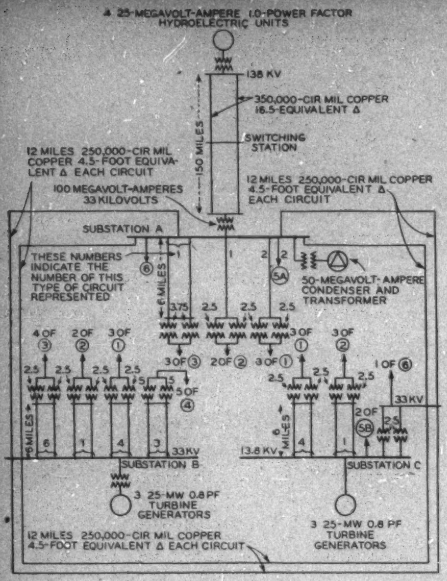
7. It is well known that in systems using long heavily loaded feeders, capacitors offer the largest gains. This study indicates that in systems where such feeders are eliminated mainly by employing the unit- or small-substation principle of design, the use of kilovar source near the load still is justified on an over-all economic basis, from the standpoint of both first cost and operating efficiency. Thus, systems using modern design extensively may use to an advantage a coordinated system program of kilovar planning.

8. System incremental load losses are twice the actual per-unit load losses in the regions of practical system operation. This

Paper 44-23, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE winter technical meeting, New York, N. Y., January 24-28, 1944; previously presented at the AIEE Southern District techical meeting, Roanoke, Va., November 16-18, 1943. Manuscript submitted September 17, 1943; made available for printing November 26, 1943.

T. W. SCHROEDER, J. W. BUTLER, AND N. H. MEYERS are all of the central station engineering department, General Electric Company, Schenectady, N. Y., where Mr. Schroeder and Mr. Butler are sponsor engineers, and Mr. Meyers is in charge of the network analyzer.

The authors acknowledge the assistance of O. B. Falls in the electrical design of the feeder circuits used in this study.


4 25-MEGAVOLT-AMPERE 1.0-POWER FACTOR HYDROELECTRIC UNITS
138 KV
350,000-CIR MIL COPPER 16.5-EQUIVALENT Δ
150 MILES
SWITCHING STATION
12 MILES 250,000-CIR MIL COPPER 4.5-FOOT EQUIVALENT Δ EACH CIRCUIT
100 MEGAVOLT-AMPERES 33 KILOVOLTS
12 MILES 250,000-CIR MIL COPPER 4.5-FOOT EQUIVALENT Δ EACH CIRCUIT
SUBSTATION A
THESE NUMBERS INDICATE THE NUMBER OF THIS TYPE OF CIRCUIT REPRESENTED
6 MILES
50-MEGAVOLT-AMPERE CONDENSER AND TRANSFORMER
4 OF 2 OF 3 OF
3 OF 2 OF 3 OF 1 OF
5 OF
33 KV
6 MILES
13.8 KV
SUBSTATION B
SUBSTATION C
3 25-MW 0.8 PF TURBINE GENERATORS
3 25-MW 0.8 PF TURBINE GENERATORS
12 MILES 250,000-CIR MIL COPPER 4.5-FOOT EQUIVALENT Δ EACH CIRCUIT

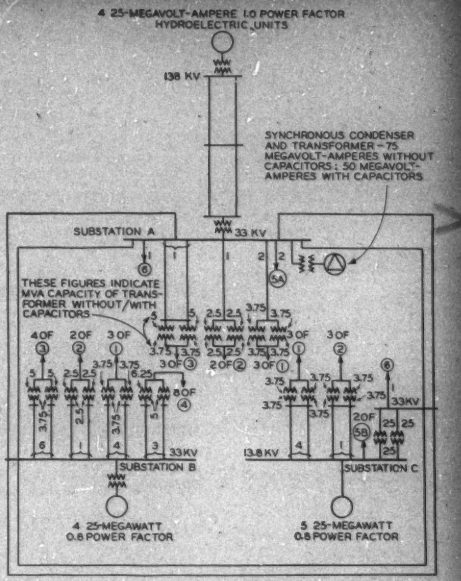

4 25-MEGAVOLT-AMPERE 1.0 POWER FACTOR HYDROELECTRIC UNITS
138 KV
SYNCHRONOUS CONDENSER AND TRANSFORMER—75 MEGAVOLT-AMPERES WITHOUT CAPACITORS; 50 MEGAVOLT-AMPERES WITH CAPACITORS
SUBSTATION A
33 KV
THESE FIGURES INDICATE MVA CAPACITY OF TRANSFORMER WITHOUT/WITH CAPACITORS
4 OF 2 OF 3 OF
3 OF 2 OF 3 OF 1 OF
8 OF
33 KV
13.8 KV
SUBSTATION B
SUBSTATION C
4 25-MEGAWATT 0.8 POWER FACTOR
5 25-MEGAWATT 0.8 POWER FACTOR

Figure 1. System layout. Present loads

All 33 kv is overhead. Six-mile circuits from generator to feeder substations are overhead; 4/0 copper 3.5 feet equivalent Δ spacing

Feeder Loads—Present

Circled Number	Type	Kilowatts	Kilovars
1	Residential	1,000	483
2	Commercial	1,000	750
3	Industrial	1,000	882
4	Commercial network	15–1,000	750
5A	13.8-kv industrial, 33-kv line	13,000	11,500
5B	13.8-kv industrial, 13.8-kv line	13,000	11,500
6	33-kv industrial, 33-kv line	14,000	12,400

Figure 2. System layout. Future loads with and without capacitors. Other details same as Figure 1

Feeder Loads—Future

Circled Number	Type	Kilowatts	Kilovars	Kilovars With Capacitors
1	Residential	1,800	876	335
2	Commercial	1,800	1,350	870
3	Industrial	1,500	1,350	490
4	Commercial network	24–1,100	825	533
5A	13.8-kv industrial, 33-kv line	19,500	17,250	9,460
5B	13.8-kv industrial, 13.8-kv line	19,500	17,250	9,460
6	33-kv industrial, 33-kv line	21,000	18,600	10,140

applies for circuits that maintain voltage by kilovar supply at either end, as well as for circuits using a regulator at the sending end to maintain receiver voltage.

Statement of the Problem

Description of System

1. General. The system was set up and studied, as shown in detail in Figures 1 and 2. It is composed of three major load areas, each with a present load of about 50,000 kw and each connected to the other by a double-circuit 33-kv belt line 12 miles in length. Two of the load areas are supplied by a local steam-generating plant each, and the third by a hydroelectric plant 150 miles distant supplying its kilowatt requirements over a two-circuit 138-kv line, with an intermediate switching station, needed for transient stability. Kilovar requirements of this load area are supplied by a synchronous condenser feeding the 33-kv substation bus. Each generating plant is capable of carrying the load requirements of its own area; hence, power flow over the belt lines is restricted to emergency conditions. Most systems would generally operate part of its subtransmission facilities loaded during normal peak-load conditions, the effect of which would be to favor the capacitor case; so the results are considered very conservative.

2 Feeders. Types, loads, and distribution among substations: Feeder types and loads are classified in the tabulations accompanying Figures 1 and 2 for present and future loads, respectively. The design and performance details of each type of feeder, for present load, future load without capacitors, and future load with capacitors, are given in Figures 3 to 9, inclusive.

Table I indicates the distribution of types of loads and feeders among the three substations.

For purposes of this study it was deemed satisfactory in the interests of simplicity to use the same feeder of each type at all three substations. This, of course, is not a condition that would occur in practice, but if the feeder length and load are considered an average value, the results produced should reasonably approach those that would obtain on an actual system.

Alternative Methods of Handling Load Growth

Figures 3 through 9 indicate the alternative methods of providing for future load growth in the various feeders, and the detailed changes required for each method are listed in Table II. For the no-capacitor case the addition or enlargement of circuits and transformers and/or voltage regulators was resorted to in order to overcome the voltage drop or thermal-capacity limitations. For the

capacitor case these limitations were overcome entirely or in part with capacitors, depending upon the details of each individual case.

These feeders were then represented as loads on the system, as shown in Figure 2, set up on the network analyzer. The normal and emergency performance of the system could then be studied with and without capacitors, and the effect of these capacitors on the system evaluated in terms of subtransmission system and distribution substation capacity needed. Table III and Figure 2 summarize the detailed changes needed to the system to enable it to carry the future loads of the feeders designed with and without capacitors.

Present and Future Loads

Details of individual feeder designs are given in the figures; hence, they need not be discussed here. It may be noted that the margin for growth beyond present loads is not necessarily the same in each of the feeders, nor is the percentage of growth to future loads exactly the same among the feeders. This fact does not affect the qualitative result of the economic comparison between the use of capacitors and the use of other means to provide for the load growth, but it obviously might affect the degree of the economic unbalance of the two methods. The values of present and future loads were taken at random; since, on an actual system they could, of course, be any value over a given period of time and would probably not be the same on each of the different types of feeders.

It is fair to expect, however, that feeder and system capacity be reasonably equally used up, that is, the margin for growth beyond future loads be the same, regardless of the method used to provide for the load increases. This is, in general, true, as will be shown by the following brief comparative comments on the margin remaining in each type of feeder, for the two methods. The numbers identifying the feeder types in Figure 3 through 9 correspond to the following numbered sections:

1. Residential Feeder. Changing single-phase laterals to three phase to cut down unregulated voltage drop in these sections reduces the voltage drop more than the simple addition of enough capacitors at the end of existing single-phase laterals to make the voltage drop acceptable, as was done in the capacitor case. This is not the discrepancy it first appears to be, however, because the future load is about the ultimate for the load area (as indicated by the load density) served by the feeder, and, even if this were not the case, the cost of achieving the same voltage drop with capacitors, as compared with changing over to three-phase laterals, would still be less.

2. Commercial Feeder. Cable ampere capacity is the limitation to increased load. If a parallel cable equal in size to the original were run, the capacity would be increased from 275 amperes to 550 amperes, whereas the capacitors added simply brought the future uncorrected load current of 312 amperes back to 275 amperes. Thus, by adding the cable, provision would be made for an added load of 1,700 kva above the 1,000-kva increase.

3. Industrial Feeder. Voltage drop limits load on this type feeder. A regulator of proper ampere capacity for future load is installed when the load grows. The regulator rating is the limiting factor for further growth. Similarly, only enough capacitors are added in the capacitor case to hold the voltage drop to the adopted values. No margin is thus left for additional load without adding equipment for either case.

4. Commercial Network. Capacitors are added in capacitor case at the four-kilovolt network supply busses without changing the network design; hence, there is no difference in margin between the two cases.

5a. 13.8-Kv Consumer Fed From 33 Kv. Additional transformer capacity was added for a 50 per cent load increase such that, with the addition of fans, a 100 per cent load increase could be taken on the basis of one line and one transformer out; 2,600 kva of capacitors could be added in the capacitor case with an emergency (one line and transformer out) full-load voltage drop of 12 per cent, but, in the no-capacitor case, emergency operation at 100 per cent load increase would result in a current through the

Table I. Types of Feeders, Feeder Loads, and Distribution of Load Among Substations

Feeder Number	Feeder Type	Number at This Station	Load of This Type at This Substation: Present Kilowatts	Present Kilovars	Present Power Factor	Future Without Capacitors Kilowatts	Future Without Capacitors Kilovars	Future Without Capacitors Power Factor	Future With Capacitors Kilowatts	Future With Capacitors Kilovars	Future With Capacitors Power Factor
			Substation A								
1	Residential	6	6,000	2,890	0.91	10,900	5,370	0.896	10,870	2,044	0.985
2	Commercial	2	1,988	1,496	0.80	3,620	2,760	0.795	3,600	1,740	0.90
3	Industrial	3	3,030	2,610	0.758	4,490	3,370	0.80	4,370	1,210	0.975
4	Commercial network	0									
5a	Industrial HTP**	2	24,880	21,560	0.756	39,800	34,500	0.755	39,000	18,300	0.895
5b	Industrial HTP	0									
6	Industrial HTP	1	13,970	12,190	0.753	21,200	18,300	0.755	20,900	9,900	0.904
	Total		49,868	40,746	0.774	80,010	64,300	0.778	78,740	35,396	0.914
			Substation B								
1	Residential	12	12,020	5,860	0.898	21,800	11,200	0.89	21,900	4,008	0.903
2	Commercial	2	2,018	1,506	0.30	3,590	2,710	0.798	3,600	1,760	0.897
3	Industrial	24	23,840	20,500	0.758	36,300	27,000	0.802	36,000	11,800	0.95
4	Commercial network	15/24*	14,960	11,490	0.793	26,600	19,700	0.803	26,400	12,800	0.90
5a	Industrial HTP	0									
5b	Industrial HTP	0									
6	Industrial HTP	0									
	Total		52,838	39,356	0.802	88,290	60,610	0.829	87,900	30,268	0.945
			Substation C								
1	Residential	12	12,320	6,060	0.896	22,100	10,800	0.897	21,900	4,208	0.90
2	Commercial	3	2,992	2,239	0.80	5,500	4,000	0.808	5,470	2,570	0.904
3	Industrial	0									
4	Commercial network	0									
5a	Industrial HTP	0									
5b	Industrial HTP	2	26,080	22,960	0.75	39,000	34,500	0.749	38,900	18,800	0.90
6	Industrial HTP	1	13,960	11,890	0.761	21,200	18,000	0.762	21,000	10,200	0.90
	Total		55,352	43,149	0.788	87,800	67,300	0.795	87,270	35,678	0.927

*Number of feeders with future loads.

**HTP stands for "high-tension (voltage) power."

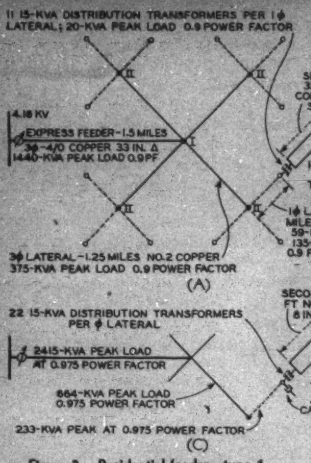

11 15-KVA DISTRIBUTION TRANSFORMERS PER 1φ LATERAL; 20-KVA PEAK LOAD 0.9 POWER FACTOR
SECONDARY 350-FT NO. 4 COPPER 8 IN. 16 IN. SPACING
4.16 KV
EXPRESS FEEDER-1.5 MILES
3φ-4/0 COPPER 33 IN. Δ
1440-KVA PEAK LOAD 0.9 PF
14 CUSTOMERS PER TRANSFORMER
1φ LATERAL-1.5 MILES NO. 2 COPPER 59-IN. SPACING 135-KVA PEAK 0.9 POWER FACTOR
3φ LATERAL-1.25 MILES NO. 2 COPPER 375-KVA PEAK LOAD 0.9 POWER FACTOR
(A)
22 15-KVA DISTRIBUTION TRANSFORMERS PER φ LATERAL
SECONDARY 175-FT NO. 4 COPPER 8 IN./16 IN.
2415-KVA PEAK LOAD AT 0.975 POWER FACTOR
14 CUSTOMERS PER TRANSFORMER
864-KVA PEAK LOAD 0.975 POWER FACTOR
45-KVA CAPACITOR
233-KVA PEAK AT 0.975 POWER FACTOR
(C)

Figure 3. Residential feeder—type 1

single line of about 600 amperes with a 13.6 per cent voltage drop.

5b. 13.8-Kv Consumer Fed From 13.8 Kv. Voltage drop under emergency condition of one circuit out with future load is considered about maximum permissible and nearly the same for either case; hence, there is no room for increased loads either way without additional investment.

6. 33-Kv Consumer Fed From 33 Kv. No change to this feeder was necessary for it to carry the future load, but for the capacitor case a bank was added arbi-

(A). Present

Voltage drops at feeder peak:
Secondary three per cent
Distribution transformer 3.2 per cent
One-phase lateral 3.9 per cent
Three-phase lateral 2.9 per cent } *
Express section 6.8 per cent }
* Regulator compensates for these
Type 1 feeder. Present diversified peak at system peak 1,110 kva at 0.9 power factor = 1,000−*j*483 kw (neglecting losses)

(C). Future with capacitors. Otherwise same as present

Voltage drops (at feeder peak)
Secondary 1.5 per cent
Distribution transformer 3.2 per cent
One-phase lateral 5.3 per cent (7.3-2 due capacitor)
Three-phase lateral 5.5 per cent } *
Express section 12.3 per cent }
* Regulator compensates for these
Type 1 feeder future diversified load at system peak = 1,830 kva at 0.985 power factor = 1,800−*j*316 kw (neglecting losses)

trarily at the end of the feeder because of the large load kilovar requirement. This would permit about 8,800 kva of load at the original power factor to be added after future load arrived in the capacitor case, but none could be added in the no-

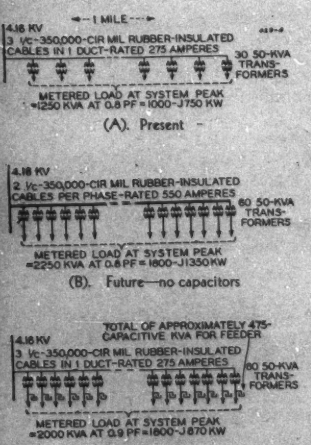

1 MILE
4.16 KV
3 Vc-350,000-CIR MIL RUBBER-INSULATED CABLES IN 1 DUCT-RATED 275 AMPERES
30 50-KVA TRANSFORMERS
METERED LOAD AT SYSTEM PEAK =1250 KVA AT 0.8 PF = 1000−J750 KW
(A). Present
4.16 KV
2 Vc-350,000-CIR MIL RUBBER-INSULATED CABLES PER PHASE-RATED 550 AMPERES
60 50-KVA TRANSFORMERS
METERED LOAD AT SYSTEM PEAK =2250 KVA AT 0.8 PF = 1800−J1350 KW
(B). Future—no capacitors
TOTAL OF APPROXIMATELY 475-CAPACITIVE KVA FOR FEEDER
4.16 KV
3 Vc-350,000-CIR MIL. RUBBER-INSULATED CABLES IN 1 DUCT-RATED 275 AMPERES
60 50-KVA TRANSFORMERS
METERED LOAD AT SYSTEM PEAK =2000 KVA AT 0.9 PF = 1800−J870 KW
(C). Future—with capacitors

Figure 4. Commercial feeder, 4,160 volts—type 2

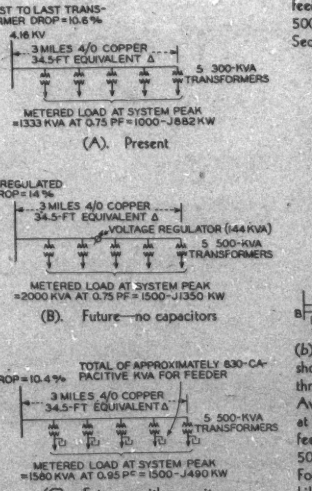
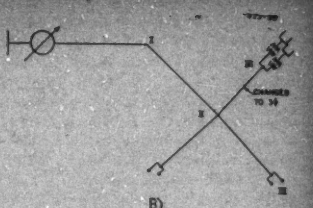
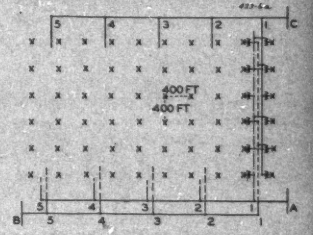

FIRST TO LAST TRANSFORMER DROP = 10.6 %
4.16 KV
3 MILES 4/0 COPPER
34.5-FT EQUIVALENT Δ
5 300-KVA TRANSFORMERS
METERED LOAD AT SYSTEM PEAK =1333 KVA AT 0.75 PF = 1000−J882 KW
(A). Present
UNREGULATED DROP = 14 %
3 MILES 4/0 COPPER
34.5-FT EQUIVALENT Δ
VOLTAGE REGULATOR (144 KVA)
5 500-KVA TRANSFORMERS
METERED LOAD AT SYSTEM PEAK =2000 KVA AT 0.75 PF = 1500−J1350 KW
(B). Future—no capacitors
TOTAL OF APPROXIMATELY 830-CAPACITIVE KVA FOR FEEDER
DROP = 10.4 %
3 MILES 4/0 COPPER
34.5-FT EQUIVALENT Δ
5 500-KVA TRANSFORMERS
METERED LOAD AT SYSTEM PEAK =1560 KVA AT 0.95 PF = 1500−J490 KW
(C). Future—with capacitors

Figure 5. Industrial feeder, 4,160 volts—type 3

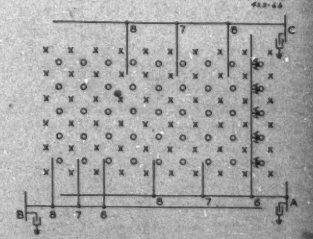


(B). Future without capacitors. Otherwise same as present

Drops (at feeder peak):
Secondary 1.5 per cent
Distribution transformer 3.2 per cent
Three-phase lateral II–III 7.3 per cent
Three-phase lateral I–II 5.5 per cent } †
Express section 12.3 per cent }
† Type 1 feeder future diversified load at system peak = 2,010 kva at 0.9 power factor = 1,800−*j*876 kw (neglecting losses)



(a). Present—15 primary (4 kv) feeders—three-conductor 350,000 circular-mil cable average metered feeder load at system peak = 1,250 kva at 0.8 power factor. x indicates feed-in point to secondary network through 500-kva 4,160/120/208-volt transformer. Secondary grid uses two 250,000-circular-mil single-conductor cables per phase



(*b*). Future with and without capacitors shows added feeders only. Add nine three-conductor 350,000-circular-mil feeders. Average load of added feeders = 1,575 kva at 0.8 power factor. o indicates added feed-in points to added network through 500-kva 4,160/120/208-volt transformer. For with-capacitor case add 2,340 capacitive kilovolt-amperes at each of the three 4,160-volt supply busses, *A*, *B*, and *C*

Figure 6. Commercial network—type 4

Table II. Summary of Physical Changes in Feeder Circuits and Their Estimated Installed Costs to Handle Future Loads

Feeder Number	Feeder Type	Total Number This Type	Changes to Feeder Without Capacitors	Cost (Dollars)	Changes to Feeder With Capacitors	Cost (Dollars)	Total Cost (Thousands of Dollars) Without Capacitors	With Capacitors
1	Residential	30	1. Split the secondary runs		1. Split the secondary runs			
			2. Add 132 15-kva 2,400/120-240-volt transformers	24,000	2. Same as for without capacitors	24,000		
			3. Change 18 miles of one-phase lateral to three-phase and reconnect half or original transformers	10,500	3. Add 540-kva outdoor distribution capacitors in 45-kva banks with hangers and one cutout per bank	2,300		
			4. Add 2,880 kva, 10 per cent induction regulator	10,000	4. Same as for without capacitors	10,000	1,335	1,089
2	Commercial	7	1. Add one single-conductor 350,000-circular mil varnished-cambric lead-covered cable per phase in existing one-mile duct	10,400	1. Add 498 kva of 7.5 kva 230 volts at 208-volt capacitor units in nine banks of nine units each with cutouts	9,300		
			2. Add 30 50-kva 4,160/120–208 volt transformer with cutout	11,500	2. Add 30 50-kva transformers	11,500	153.3	145.6
3	Industrial	27	1. Add 1,400 kva 10 per cent induction regulator	5,500	1. Add 900 kva of outdoor capacitors in 180-kva banks with hangers and cutouts	5,000	148.5	135
4	Commercial network	15 present 24 future	1. Add nine 3-conductor 350,000-circular mil cable feeders 2,000 feet long in new ducts	60,300	1. Same as without capacitors	60,300		
			2. Add 45 500-kva network transformers and protectors and vaults	517,500	2. Same as without capacitors	517,500		
					3. Add three banks of 2,340 kva of capacitors in housed racks at low side (1,460 volts) of feeder transformers with breakers	46,000	577.8	623.8
5a	13.8-kv customer fed by 6-mile 33-kv line	2	1. Add two 10-megavolt-ampere 33/13.8-kv transformers, including installation and station additions	44,000	1. Add two 7.5 megavolt-ampere 33/13.8-kv transformers, including installation and station additions	35,000		
					2. Add three 2,520-kva capacitor banks	49,600	88	169.2
5b	13.8-kv customer fed by 5-mile 13.8-kv lines	2	1. Add one 5-mile, 250,000 circular mil copper 13.8-kv line	26,500	1. Add three 2,520-kva capacitor banks	49,600		
			2. Add two 1,000,000-kva 15-kv circuit breakers, including station additions	22,000			86	99.2
6	33-kv customer fed by 6-mile 33-kv lines	2			1. Add 8,280-kva capacitor bank	54,300		108.6
							2,388.6	2,370.4

capacitor case because of voltage drop and conductor thermal limitations.

It may be noted that for feeder type 2 the no-capacitor case shows the larger margin, whereas in type 6 the reverse is true. Also a more favorable emergency operating condition obtains under ultimate load conditions for feeder type 5*a* for the capacitor case than for the no-capacitor case.

Summary of Results

System Investments to Provide for Load Growth

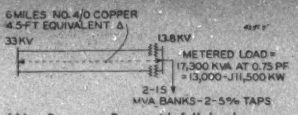
In going from the present to the future system it was necessary to add the same amount of generating capacity at stations *B* and *C* with either method of providing for load growth. In view of this, the cost of the plant additions was not included in the comparison. This addition was one 25-megawatt unit at substation *B* and two 25 megawatt units at substation *C*.

The installed cost of changes to the feeders, substations, and subtransmission facilities to carry future loads with and without capacitors is itemized in Tables II and III. It is realized that the costs selected may differ considerably from those which would obtain on specific actual systems because of local conditions, but it is believed that the costs chosen are representative. A brief over-all summary of the investment results may be found in Table IV.

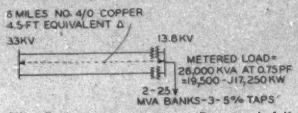
It is again emphasized that the major gains indicated in Table IV appear in parts of the system other than the feeders because of the principle of system design adopted. Small substations with relatively short feeders are the general principles involved. This has generally been called the unit-substation or load-center type of distribution. This principle results in a relatively efficient distribution system with fewer of the properties usually conducive to capacitor gains, and, as seen, any substantial benefit must necessarily appear elsewhere in the system. The loss data given in the following section further indicate the high efficiency of this system in relation to the average actual system being operated. The loss at time of peak for the future case without capacitors is only

Table III. Summary of Physical Changes to Transmission Facilities and Estimated Installed Costs

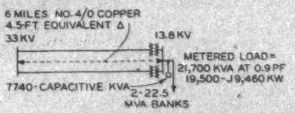
Changes If Capacitors Are Not Used	Cost (Dollars)	Changes If Capacitors Are Used	Cost (Dollars)
1. Add 25 megavolt-ampere synchronous condenser, transformer, and circuit breaker	212,000	Add 12 2,500-kva 33/4.16-kv transformers	102,000
		Add 5 2,500-kva 13.8/4.16-kv transformers	37,500
2. Add fans to two 3,750-kva transformers for 5,000 kva at 950	1,900		
3. Add six 2,500-kva 33/4.16-kv transformers	51,000		
4. Add six 5,000-kva 33/4.16-kv transformers	78,000		
5. Add fans to three 5,000-kva units for 6,250 kva at 1,100	3,300		
6. Add five 2,500-kva 13.8/4.16-kv transformers	37,500		
Total	383,700	Total	139,500



(A). Present. Drop with full load on one circuit = 10.9 per cent



(B). Future—no capacitors. Drop with full load on one circuit = 13.6 per cent



(C). Future with capacitors. Drop with full load on one circuit = 9.1 per cent

Figure 7. 13.8-kv industrial customer fed from 33 kv—type 5a

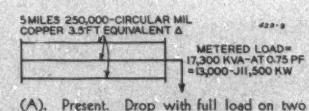
0.13 per unit. Hence, one should not conclude too hastily that the gains (as to magnitude and location) obtained in this system through a general kilovar program will apply to his particular system. Power systems having the more usual type of distribution, that is, longer feeders, will show comparatively greater benefit to the distribution system itself from the application of capacitors thereto.

System Losses

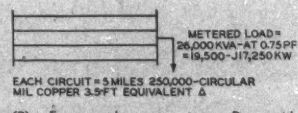
Table V summarizes the metered and generated loads and losses for the various cases.

The difference in load or metered kilovars between the capacitor and no-capacitor cases represents the kilovars of capacitors employed on the feeders and at distribution substations. This is 91,100 kva. The difference in kilovars supplied by generators for the two cases is 125,100 kilovars, so a kilovar loss of 34,000 obtains for the no-capacitor case.

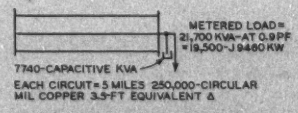
The value of the reduction in losses of 7,900 kw and 34,000 kilovars, resulting from the load kilovars being supplied near the load, was not accounted for in the economic comparison because of the considerable variation in what is considered a fair cost for losses among engineers. At any given rate, either on a capitalized investment or energy charge basis, the power losses may, of course, be evaluated readily. Similarly, the reactive power losses may be charged for on a basis of system investment required to supply them, or simply in terms of the cost of capacitors or condensers of ratings equal to the difference in losses. In any event, this difference in losses represents a difference in operating margins, and may be evaluated accordingly.



(A). Present. Drop with full load on two circuits = 13.7 per cent



(B). Future with no capacitors. Drop with load on three circuits = 13.7 per cent



(C). Future with capacitors. Drop with full load on two circuits = 14 per cent

Figure 8. 13.8-kv industrial customer fed from 13.8 kv—type 5b

Generating-Plant Margins—Normal and Emergency Operation

Table III shows no change in generating capacity, because, for the system studied, the future kilowatt requirements demanded the same number of generators at stations *B* and *C* whether or not distribution capacitors were used. Similarly, the hydroelectric plant capacity required would be the same, since economics and operating requirements normally tend toward practically unity-power-factor long-distance transmission. However, at substation *A* a larger synchronous condenser is needed for the no-capacitor case to supply the required kilovars to this load area.

The difference in kilovar burdens and system-loss requirements on steam-generating plants *B* and *C*, therefore, evidences itself in this study in greater margins for future growth and for emergency conditions. The evaluation of this is left to the reader, but actually it could have been, and normally would be, evaluated in terms of the cost of generator or kilovar supply capacity installed at the station. If the generators can carry added kilowatt load when their kilovar load is reduced, it could be measured in terms of generator capacity costs.

In future steam-station loads with no capacitors, normal margin is one machine (spinning reserve) of $25-j\ 18.75$ megawatts. (The minus sign on reactive quantities represents magnetizing reactive kilovolt-amperes throughout this paper.)

In future steam-station loads with capacitors, normal margin is $31.7-j\ 61.9$ megawatts, which includes the unit held in spinning reserve.

On this basis, if it is assumed that the boilers and steam-unit prime movers have sufficient capacity, the generators can supply the load requirements under low-water conditions with two hydroelectric

Table IV

Item	With Capacitors	Without Capacitors
Cost of changes to feeders for a 100,000-kw system load increase	$2,370,400	$2,388,600
Cost of changes to rest of system, exclusive of power plant for this load increase	$ 139,500	$ 383,700
Total cost, exclusive of power plant	$2,509,900	$2,772,300
Cost per kilowatt of added transmission- and distribution-system capacity	$ 25.10	$ 27.72

Table V. Summary of Metered and Generator Loads

	Station	Megawatts	Reactive Megavolt-Amperes
Present metered loads	A	49.87	40.75
	B	52.84	39.36
	C	55.35	43.24
	Total	158.06	123.35
Present generation	A	58.0	8.2
	B	57.5	52.0
	C	58.8	46.0
	Condenser		51.5
	Total	174.3	157.7
		158.1	123.4
	Losses	16.2	34.3
Future without capacitors loads	A	80.01	64.3
	B	88.29	60.6
	C	87.9	67.3
	Total	256.1	192.2
Generation	A	91.5	4.9
	B	100.0	88.8
	C	98.0	82.0
	Condenser		76.0
	Total	289.5	251.7
		256.1	192.2
	Losses	33.4	59.5
Future with capacitors loads	A	78.7	34.19
	B	87.9	31.27
	C	87.3	35.68
	Total	254.0	101.14
Generation	A	86.2	−10.9
	B	97.6	44.9
	C	95.7	45.8
	Condenser		46.8
	Total	279.5	126.6
		254.0	101.1
	Losses	25.5	25.5
Losses without capacitors		33.4	59.5
Losses with capacitors		25.5	25.5
Reduction in losses with capacitors		7.9	34.0
Metered kilovar load without capacitors (future)			192.2
Metered kilovar load with capacitors (future)			101.1
Capacitor kilovolt-amperes added			91.1

units off if capacitors are not used, and with three hydroelectric units off if they are used. This is seen readily from the data in Figure 11 and is an example of how the generating-plant margins may be evaluated in terms of operating conditions.

Capacitors as a Stepping Stone in System Growth

The analysis reported in this paper was made on the basis of considering the cost of an addition to a system, as though its load grew 67 per cent, and the changes were almost overnight. No account was taken of the effects of providing for this ultimate increase in steps, somewhat ahead of an increment of load growth. It was assumed that this effect would be

Table VI. Δ Kilovars Per Δ Kilovolt-Ampere Per 0.05 Step in Power Factor

Δ Power Factor	Δ Kilovars Per Δ Kilovolt-Ampere
1.0 –0.95	6.2
0.95–0.90	2.68
0.90–0.85	2.05
0.85–0.80	1.8
0.80–0.75	1.59

The increase in kilovar capacity per kilovolt-ampere capacity in going from 0.95 to 0.90 power factor is 2.68.

Table VII. Generator Kilovolt-Amperes and Power Factor for Various Line Reactance and Load Values for Constant Kilowatts

	Circuit Reactance = 0.20		Circuit Reactance = 0.30	
Load Power Factor	Generator Kilovolt-Amperes	Generator Power Factor	Generator Kilovolt-Amperes	Generator Power Factor
1.0	1.02	0.981	1.042	0.96
0.95	1.13	0.886	1.18	0.848
0.90	1.21	0.828	1.27	0.788
0.85	1.29	0.773	1.36	0.736
0.80	1.39	0.72	1.45	0.69
0.75	1.47	0.68	1.54	0.648

the same whether the capacitor or no-capacitor method were used in providing for the load increment. Obviously, this would be difficult of evaluation, unless a knowledge of the load growth or trend with time were available. Such knowledge is, however, available on actual systems and should be made use of for the purpose described.

Actually, if this effect were evaluated, it would favor the use of capacitors, since they can be added in smaller quantities and follow the load growth more closely than regulators, transformers, lines, and cable circuits necessarily are able to do. Thus, there would be at any time somewhat less unused capacity lying idle waiting for the load to grow and use it up.

Another way of saying this is that the capacitor postpones the investment until such time as the larger equipment can be added justifiably, and it is in this way that capacitors may come to be used more in meeting system growth. Their high re-use value and great flexibility will permit them to be used on one part of a system for a time until it is enlarged and then to be moved elsewhere to repeat the process of following the load growth there.

Importance of Complete System Viewpoint

As were pointed out in the opening paragraphs of this paper, there are cases where, to meet a single requirement, and with alternate equipment available, the use of capacitors would not be justified. A study of the detailed feeder cost com-

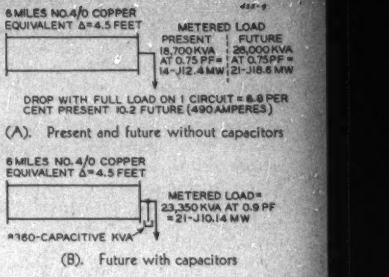


Figure 9. 33-kv customer fed from 33 kv—type 6

parisons will show examples of this. There are two cases (feeders 4 and 6) where capacitors were not needed on the feeders themselves, but they were added at this location, as it was the logical place for kilovar production in the coordinated program.

This fact emphasizes the need for definite correlation in power-system design groups between those responsible for distribution-system design and those who design and operate the subtransmission, transmission, and generation portions of the system—an over-all viewpoint taken by all of these groups will make for added system economy.

How Far Should Load Kilovars Be Transmitted?

In systems where the loads are relatively near the generating plants, the question may be raised concerning the wisdom of supplying kilovars with capacitors instead of with the generators. The analysis reported in this paper answers

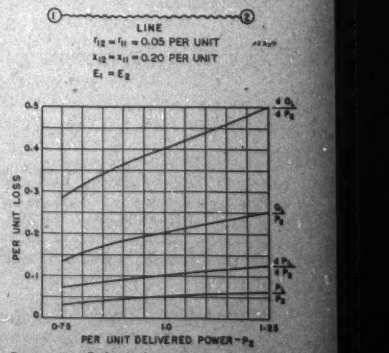


Figure 10. Relation between incremental and actual power losses over a circuit. Voltages maintained equal at points 1 and 2 by kilovar control

this question for a particular system in detail. The following discussion presents a few additional notes from which a quick picture of the general problem may be obtained.

As a basis for discussion and comparison, the data in Table VI are first presented. These figures give the incremental kilovar capacity per kilovolt-ampere required to be built into equipment such as cables, transformers, and generators at constant kilowatt load for certain finite steps in power factor.

On the basis that equipment costs are somewhat proportional to its kilovolt-ampere rating, these figures indicate the degree to which kilovar capacity becomes increasingly expensive at the lower power factors. This is another way of saying the well-known fact that power-factor improvement tends to become uneconomical at the higher power factors.

When Generator Output Is Stepped Up Through Transformers

A unity power-factor load supplied through a 0.30 per unit reactance requires that 1.0 kw +0.30 kilovar be supplied by the generator, corresponding to 0.96 power factor. Following this reasoning, for several load power factors and two values of reactance, gives the data in Table VII.

Since it takes only two transformers to total approximately 0.20 per unit reactance, 0.30 per unit would not be uncommon for the total of a subtransmission circuit where line loading is generally relatively heavy. And with 0.30 per unit it is required that the load power factor be 0.95 if the generator power factor is to be approximately 0.85. Thus, line I^2X losses are not small and are to be respected.

When Load Is Supplied at Generator Voltage

Under this condition for the case of overhead lines, one cannot readily make an analysis in view of the difficulty of establishing the rating and the effect of power factor on the rating of such a line. Purely on the basis of line reactance, however, the data in Table VII are applicable.

Cable circuits, where thermal capacity is the limiting factor, may be approached as follows. A conservative figure for 3/*C* cable, being operated at the most economical loading, is approximately $1.45 per kilovolt-ampere-mile. An additional charge of about $0.45 per kilovolt-ampere-mile for ducts brings the figure to $1.9 per kilovolt-ampere-mile total. When only these figures are used, and the costs of terminal equipment, such as generators are ignored, the data in Table VIII can be determined readily. These figures give the incremental cost chargeable to incremental kilovar per 0.05 step in power factor for three cable mileages. For other cable lengths costs at a particular power-factor increment are directly proportional to length.

These figures give an indication as to how far loads at various power factors can be supplied by cables to balance the investment necessary in capacitors to furnish the incremental kilovars, namely, approximately $5 or $6 per kilovar. For instance, from the table, at four miles, the load power factor should be improved to approximately 0.85, because below this the incremental kilovar costs favor capacitors, and at approximately eight miles the power factor should be 0.95, which somewhat indicates the limit of kilovar transmission through cable.

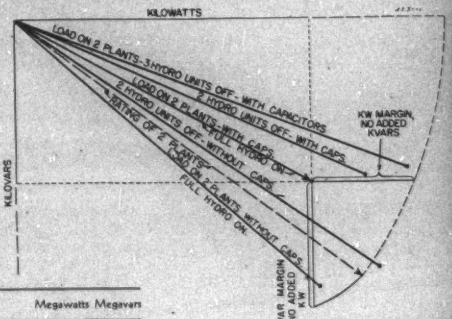
The kilovolt-ampere loadings of the cables in this discussion correspond approximately to those whose I^2X losses will consume the cable charging kilovolt-amperes. Thus, the cable line-charging kilovolt-ampere is not ignored.

Table VIII. Dollars Per Kilovar Investment Chargeable Per 0.05 Step in Power Factor for Three Mileages

Δ Power Factor	4 Miles	8 Miles	12 Miles
1.0 –0.95	1.21	2.42	3.63
0.95–0.9	3.08	6.6	9.24
0.9 –0.85	4.13	8.26	12.39
0.85–0.8	5.2	10.4	15.6
0.80–0.75	6.22	12.4	18.66

At 0.95 power factor the investment chargeable per kilovar capacity for eight miles is $2.42, and the charge for the additional kilovar capacity required in going from 0.95 to 0.9 power factor is $6.18.

Figure 11. Summary of steam-plant loadings under normal and emergency conditions


KILOWATTS
KILOVARS
LOAD ON 2 PLANTS-3 HYDRO UNITS OFF-WITH CAPACITORS
LOAD ON 2 PLANTS-WITH CAPS.
2 HYDRO UNITS OFF-WITH CAPS.
4 HYDRO UNITS OFF-WITH CAPS.
FULL HYDRO ON
2 PLANTS OFF-WITHOUT CAPS.
LOAD ON 2 PLANTS-WITHOUT CAPS.
FULL HYDRO ON
KW MARGIN, NO ADDED KVARS
KVAR MARGIN, NO ADDED KW

Item	Megawatts	Megavars
Rating of two plants	225	169
Load on two plants, two hydro-electric units off.		
Without capacitors	235.2	161.6
With capacitors	228.8	101.6
Load on two plants, three hydro-electric units off		
With capacitors	254.3	97.6

Appendix

Incremental Kilovar and Kilowatt Losses

Case I. Load Voltage Maintained by Raising Sending-End Voltage

This case characterizes a circuit with a regulator or load-ratio control at the substation for maintaining voltage in a remote load area.

$$P_2 = \frac{e_2^2 \cos \theta_2}{Z_1} = \text{load kilowatts} \qquad (1)$$

where Z_2 = magnitude of load impedance and θ_2 = load power factor. Neglecting line-charging current

$$P_L = \frac{e_2^2 Z_1}{Z_2^2} = \text{power loss in } Z_1\text{, the line impedance} \qquad (2)$$

From 1

$$Z_2 = \frac{e_2^2 \cos \theta_2}{P_2}$$

so

$$P_L = \frac{P^2{}_2 Z_1}{e_2^2 \cos^2 \theta_2} \qquad (3)$$

and the incremental loss with respect to load kilowatts is,

$$\frac{dP_L}{dP_2} = \frac{2P_2 Z_1}{e_2^2 \cos^2 \theta_2} \qquad (4)$$

From 3

$$\frac{P_L}{P_2} = \frac{P_2 Z_1}{e_2^2 \cos^2 \theta_2} = \text{actual power loss in per unit of load kilowatts} \qquad (5)$$

If equation 4 is divided by equation 5, the ratio of the incremental to the actual power loss is found to be 2, a well-known result.

This analysis also applies for the load-loss component of transformer and machine losses.

Case 2. Terminal Voltages Maintained by Kilovar Control

This case characterizes a subtransmission or transmission circuit utilizing kilovar sources, such as synchronous condensers, at either end for controlling voltage.

The well-known power equations for such a circuit with power flowing from point 1 to point 2 are

$$P_1 = \frac{E_1^2}{Z_{11}} \sin \alpha_{11} + \frac{E_1 E_2}{Z_{12}} \sin (\delta_{12} - \alpha_{12}) \quad (6)$$

$$P_2 = \frac{E_2^2}{Z_{22}} \sin \alpha_{22} - \frac{E_1 E_2}{Z_{12}} \sin (\delta_{12} + \alpha_{12}) \quad (7)$$

$$Q_1 = \frac{-E_1^2}{Z_{11}} \cos \alpha_{11} + \frac{E_1 E_2}{Z_{12}} \cos (\delta_{12} - \alpha_{12}) \quad (8)$$

$$Q_2 = \frac{-E_2^2}{Z_{22}} \cos \alpha_{22} + \frac{E_1 E_2}{Z_{12}} \cos (\delta_{12} + \alpha_{12}) \quad (9)$$

P_1, P_2 = real power passing points 1 and 2

Q_1, Q_2 = reactive power passing points 1 and 2

Z_{12} = ratio of voltage at 1 to current at 2 when 2 is grounded

Z_{11} = ratio of voltage at 1 to current at 1 with 2 grounded

Z_{22} = ratio of voltage at 2 to current at 2 with 1 grounded

$$\alpha_{11} = \tan^{-1} \frac{r_{11}}{X_{11}} \qquad \alpha_{22} = \tan^{-1} \frac{r_{22}}{X_{22}}$$

δ_{12} = angle between voltage E_1 and E_2

$$\alpha_{12} = \tan^{-1} \frac{r_{12}}{X_{12}}$$

For a line section with no intermediate loads $Z_{11} = Z_{22}$, and when equal voltages held at either end are assumed, the equations for power loss are

$$P_L = \frac{2E^2}{Z_{11}} \sin \alpha_{11} - \frac{2E^2}{Z_{12}} \sin \alpha_{12} \cos \delta_{12} \quad (10)$$

$$Q_L = \frac{-2E^2}{Z_{11}} \cos \alpha_{11} + \frac{2E^2}{Z_{12}} \cos \alpha_{12} \cos \delta_{12} \quad (11)$$

It is desired to find the incremental power losses with respect to the receiving power P_2.

Solving for $\cos \delta_{12}$ in equation 7, there is

$$\cos \delta_{12} = \cos (\alpha_{12} + \psi) \quad (12)$$

$$\psi = \tan^{-1} \frac{\left(P_2 - \frac{E_1^2 \sin \alpha_{11}}{Z_{11}} \right)}{\left[\frac{E^2}{Z_{12}} - \left(P_2 - \frac{E^2}{Z_{11}} \sin \alpha_{11} \right)^2 \right]^{1/2}}$$

Substitute equation 12 in equations 10 and 11 and differentiate to get

$$\frac{dP_L}{dP_2} = 1 - \frac{\cos (\alpha_{12} + \psi)}{\cos \psi} \quad (13)$$

and

$$\frac{dQ_L}{dP_2} = -\left[\tan \psi + \frac{\sin (\alpha_{12} + \psi)}{\cos \psi} \right]$$

Equations 13 and 14 give the incremental power losses with respect to the delivered power, and, if equations 10 and 11 are divided by P_2, the actual power losses in per unit of delivered power are obtained. A simple relation for the ratio of the incremental to the actual power loss, as was obtained in case 1, is not evident; so, a numerical case is given, as in Figure 10, to enable a concept to be obtained as to their relative magnitudes. From the data in Figure 10 it is seen that the ratio of the incremental to the actual losses is approximately 2 for a large range of values of P_2. This fact, coupled with the factor 2 obtained in case 1, strongly tempts one to draw the general conclusion that no matter how a circuit is operated with respect to holding voltages, the ratio of the incremental to actual power losses in regions of practical operation is always approximately 2.

A Multiplied-Deflection A-C Potentiometer

R. B. MARSHALL
ASSOCIATE AIEE

THE power required for the operation of an indicating instrument frequently makes its use prohibitive because of the disturbing effect it has on the circuit being measured. If the measurement is in a d-c circuit, the difficulty is overcome readily by using a d-c potentiometer. In a-c measurements, the indicating instruments have a much greater disturbing effect on the circuit, and the use of an a-c potentiometer is very desirable. Furthermore, a-c potentiometers are very useful for measuring power in circuits where the power is too small to be measured with a dynamometer wattmeter.

Most a-c potentiometers have the disadvantage of being too complicated to be used by any but a skilled operator. They have the further disadvantage that they usually are not offered for sale as portable all-purpose instruments. Instead, a special laboratory assembly is used for each task to be performed. One of these arrangements utilizes a calibrated phase shifter. A means of phase detection must be used so that the scale on the phase shifter can be set on the proper value. In addition, the potentiometer current must be standardized for magnitude, and the standardizing process is somewhat more complicated with alternating current than it is in the case of the d-c potentiometer. In another form of the laboratory arrangement, a mutual inductor is used to produce the quadrature component of potentiometer voltage. In this case, the phase angle between two currents must be adjusted to zero, and the magnitude of the potentiometer current must be standardized.

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R. B. Marshall is associate professor in the school of electrical engineering, Purdue University, West Lafayette, Ind.

The multiplied-deflection a-c potentiometer eliminates all of these difficulties and makes the operation so simple that an inexperienced operator can make accurate measurements with ease. The instrument is portable and suitable for field work. Very little skill is necessary to make the null balance, and the operator scarcely can make a mistake in determining the results, provided he reads the three indicating instruments (voltmeter, ammeter, and wattmeter) correctly.

The designation *multiplied deflection* was adopted because indicating instruments are used, and their deflections are convenient multiples of the measured quantity. For example, 100 millivolts may be read as 100 volts on a 150-volt indicating instrument, but the reading then is divided by 1,000, as indicated on the potentiometer ratio dial. This potentiometer was developed for the purpose of measuring the impedance and power consumption of circuit elements having a fraction of an ohm of impedance. The current coil of a watt-hour meter was the first circuit element studied, and the results were so highly satisfactory that the instrument was rebuilt with a circuit-changing switch so that it also could be used for measuring high impedances. With this circuit, the impedance and core loss of a doorbell transformer or small radio transformer can be measured easily. High impedances up into the megohms are measured as readily as low impedances, and the circuit may be guarded from leakage in the customary manner, if it is desirable to do so. Numerous other applications become apparent, and some of these will be described later.

Figure 1 shows the scheme used for the measurement of a low-impedance circuit element designated as Z_x. The four terminals (two for current and two for

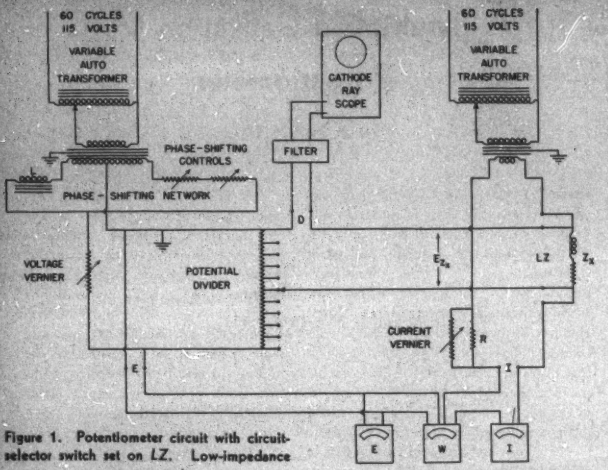

Figure 1. Potentiometer circuit with circuit-selector switch set on *LZ*. Low-impedance measurements

potential) of Z_x are connected to the *LZ* posts. In the upper right-hand part of the figure an adjustable-ratio autotransformer is connected to a two-circuit shielded transformer. The secondary winding provides a current through Z_x in series with an ammeter and the current coil of a wattmeter. This particular potentiometer is designed to provide any current up to ten amperes, but there is no basic reason why a larger current could not be used. The current through the unknown impedance is adjusted to the value required for the test at hand. Major adjustments are made with the autotransformer and minor adjustments are made with the rheostat marked "current vernier." As a result of this current, a voltage drop E_{Z_x} occurs across Z_x.

In the upper left-hand part of Figure 1, another adjustable autotransformer is used to supply voltage to a phase shifter. The phase shifter is a simple uncalibrated network which is capable of having its output voltage shifted through a little over 120 degrees. An iron-core inductor *L* is used in this network, and, in addition to having a functional part in the phase-shifting process, it offers a high reactance to any harmonics that may be introduced by the supply voltage. As a result, the wave form of the phase-shifter output voltage is as good as, or better than, that of the supply voltage. The phase shifter is capable of supplying any output current up to one ampere. This is more current than is needed by its load, which consists of a voltmeter, a wattmeter, and a potential divider, but undesirable voltage regulation during adjustment is thus made negligible. The magnitude of the output voltage of the phase shifter is varied with the adjustable-ratio autotransformer and the voltage-vernier rheostat. Major and vernier phase-shifting rheostats are provided as indicated. A potential divider is used in this circuit in very much the same manner as a volt box is used with a d-c potentiometer. The resistors that make up the potential divider are accurate to one tenth of one per cent and are noninductive.

To obtain a null balance the current through the unknown impedance is first adjusted to the correct value. The voltage (left-hand) autotransformer is then adjusted, until a reading is obtained on the upper part of the voltmeter scale. A 150-volt range is very satisfactory for the voltmeter. The potential divider is then adjusted, point by point, until its output voltage is approximately equal to E_{Z_x}. Exact balance is obtained by adjusting the voltage in both magnitude and phase position, until a zero indication is obtained on a null detector.

Any sensitive detector should be suitable for determining the point of final balance. A cathode-ray oscillograph with a gain of 1,000 in the vertical amplifier is quite satisfactory. Since the oscillograph is rather cumbersome, an electric-eye detector is more suitable for a portable potentiometer. Harmonics occurring in the voltage across Z_x are not balanced by the voltage from the potential divider. These harmonics are eliminated by the use of a filter. It will be shown later that this does not introduce any error.

When the balance has been obtained, the three indicating instruments and the potential-divider ratio N are observed. The voltmeter and wattmeter indications are then divided by N. The results are calculated from the usual formulas used with voltmeter, ammeter, and wattmeter data. Let E, I, and P indicate the instrument readings. Then

$$E_{Z_x} = E/N$$
$$P_{Z_x} = P/N$$
$$Z_x = E/NI$$
$$R_{Z_x} = P/NI^2$$
$$\text{Cos } \theta = P/EI = \text{power factor}$$
$$X_{Z_x} = Z_x \sin \theta$$

As an example of the use of these formulas, assume that the following data are obtained

$E = 90$ volts
$I = 5$ amperes
$P = 200$ watts
$N = 2{,}000$

Then $E_{Z_x} = 90/2{,}000$ volts or 45 millivolts

$P_{Z_x} = 200/2{,}000$ or 0.1 watt

$$Z_x = \frac{0.045}{5} = 0.009 \text{ ohm}$$

$$R_{Z_x} = \frac{0.1}{25} = 0.004 \text{ ohm}$$

$$\text{Cos } \theta = \frac{200}{5 \times 90} = 0.444$$

$$X_{Z_x} = 0.00807 \text{ ohm}$$

There is no correction for the potential coil or current coil of the wattmeter, because the potential is supplied from a circuit that is independent of the current circuit.

With reference to Figure 3, it may be seen that a switch is provided to change the circuits in the instrument. When the switch is set in the *LZ* position, the circuit shown in Figure 1 is obtained. Figure 2 shows the circuit that results when the switch is set in the *HZ* position. In Figure 2 the potential divider is reconnected so that it becomes a current shunt. The unknown impedance is then attached to the *HZ* terminals and is, therefore, connected in series with the current shunt. A standard 0.2-ohm noninductive resistor R_s is in series with the ammeter and wattmeter current coil, and the drop across R_s is compared with the drop across the current shunt.

In measuring a high impedance the voltage is adjusted to the value desired for the impedance at hand. Actually, the voltmeter reads the voltage across both Z_x and the current shunt. The error caused by this is negligible, since the current shunt is turned to the points of high resistance only when Z_x is exceedingly high. The current-shunt resistors

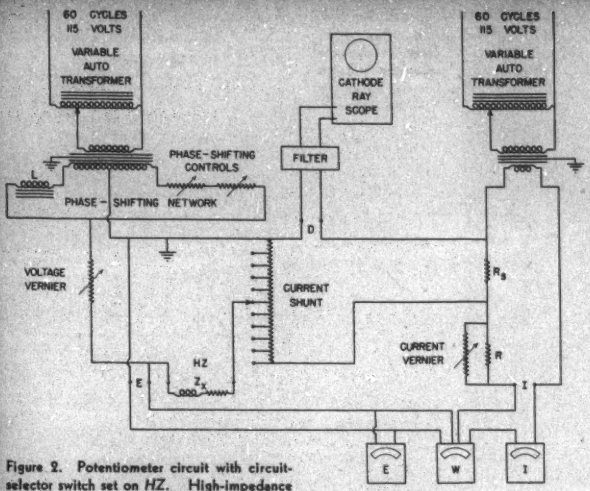

Figure 2. Potentiometer circuit with circuit-selector switch set on *HZ*. High-impedance measurements

are selected so that the error is less than 0.25 volt. The current through R_s is set at any convenient value, which causes the ammeter to read on the upper part of its scale. The current shunt is then adjusted until its voltage drop is equal approximately to the drop across R_s. Final null balance is obtained by means of the current vernier and the potential phase shifter.

The instruments used are the same as those used for measuring a low impedance, and none of the instrument connections are altered. The ratio n is the ratio of the current shunt resistance to the fixed resistor R_s. Two engraved scales are provided on the ratio dial, and care must be taken to read the correct scale. Let E, I, and P indicate the readings of the instrument

$I_{Z_x} = I/n$
$P_{Z_x} = P/n$
$Z_x = En/I$
$R_{Z_x} = Pn/I^2$
$\text{Cos } \theta = P/EI$ = power factor
$X_{Z_x} = Z_x \sin \theta$

As an example of a high-impedance measurement, suppose that a small transformer is tested and the following data are obtained:

$E = 115$ volts
$I = 4.5$ amperes
$P = 160$ watts
$n = 1{,}000$
$I_{Z_x} = 4.5/1{,}000$ amperes or 4.5 milliamperes
$P_{Z_x} = 160/1{,}000$ watts or 160 milliwatts
$Z_x = 115{,}000/4.5$ or 25,600 ohms

$$R_{Z_x} = \frac{160{,}000}{20.2} \text{ or } 7{,}930 \text{ ohms}$$

$$\text{Cos } \theta = \frac{160}{115 \times 4.5} = 0.31$$

$X_{Z_x} = 25{,}600 \times 0.95 = 24{,}300$ ohms

In Figure 3 the two adjustable-ratio autotransformers are not shown. These are attached as auxiliary equipment. The ammeter and wattmeter are connected to the posts marked *I*. The voltmeter and wattmeter are connected to the posts marked *E*. High-impedance circuit elements are attached to the two posts marked *HZ*, and low-impedance circuit elements are attached to the four posts marked *LZ*. The detector is connected to the posts marked *D*. The ventilated compartment, mounted in the back, houses the phase-shifting network. Three fuses (upper center) protect the resistors in the current shunt when the circuit of Figure 2 is used. The fuses are inserted in such a way that the fuse resistance does not affect the calibration.

Miscellaneous Applications

To measure a low voltage it is necessary to connect it only across the two inner posts of the *LZ* terminals. The circuit selector is set on *LZ*, and the balance is made without switching on the current circuit. No current is drawn from the unknown potential at balance, and the voltage is determined by reading the voltmeter and dividing by the potential-divider ratio.

To calibrate a millivoltmeter when only a standard 150-volt voltmeter is available, the standard voltmeter is connected to the *E* posts of the potentiometer. The millivoltmeter may be operated from an independent source, and the values may be measured by connecting from the millivoltmeter to the inner posts of the *LZ* terminals.

To calibrate a milliammeter when only a standard five-ampere instrument is available, it is necessary only to insert a rheostat with the milliammeter in series across the *HZ* terminals and to connect the standard ammeter to the potentiometer–ammeter terminals.

To measure leading power-factor elements of either high or low impedance, or to measure the capacitance and power factor of a capacitor, it is necessary to make a change in the range of the phase shifter. As previously stated, the phase shifter covers a range somewhat greater than 120 degrees. If a three-phase supply is available, the left-hand autotransformer can be connected to either phase, and the entire 360-degree range may be utilized. The phase shifter in the potentiometer described covers the range from in phase to 120 degrees lagging when both autotransformers are connected to the same phase. If it is desirable to measure leading power-factor elements in a location where three-phase power is not available, the construction of the phase shifter should be altered so that the inductor *L* is replaced by a capacitor. The phase shifter will then cover the range from in phase to approximately 180 degrees leading. The output voltage of the phase shifter then should be filtered to eliminate any objectionable harmonics that are amplified by the capacitor.

The impedance and power loss due to leakage and dielectric hysteresis in lead-covered cables can be measured in the same manner as a capacitor. If it is desirable to guard the insulated ends of the cable, the guard wire should be attached to ground.

The application for which this instrument was originally designed is that of measuring the burden occurring on a current transformer in a metering installation. Since the potentiometer is portable, the burden may be measured at the site of the installation simply by disconnecting the current transformer. The transformer then may be removed and calibrated in the laboratory, if a duplicate burden is provided.

Sources of Error

Since the data on the multiplied-deflection potentiometer are obtained from indicating instruments, the entire pro-

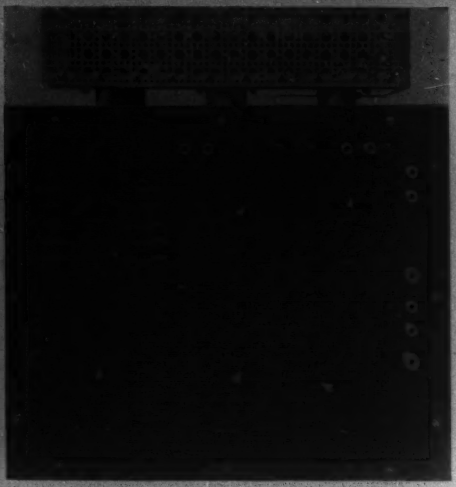

Figure 3. Top panel view of the potentiometer, exclusive of adjustable-ratio transformers, instruments, and null detector

cedure is limited in accuracy to the accuracy of these instruments. If high-grade dynamometers are used, an overall accuracy of one quarter of one per cent can be obtained. Errors in the resistors used in the potentiometer are reduced so that they are negligible compared with the instrument errors. Insulation resistance within the potentiometer must be arranged carefully to prevent leakage across the *HZ* terminals. Since the high-impedance values sometimes run into the megohm range, the insulation resistance must be in the hundreds of megohms in order to realize maximum accuracy. If desirable, these leakage paths may all be eliminated by guarding in the conventional manner. All guards should be attached to ground.

It should be noted that the transformer in the current circuit is shielded and grounded. A similarly shielded transformer is incorporated in the phase-shifting network. This precaution is necessary in order to prevent capacitance currents from feeding through the potentiometer from one autotransformer to the other.

The most irritating question pertaining to the accuracy of the instrument has to do with the handling of harmonics. This problem is not peculiar to this particular potentiometer. In fact, the problem is not a matter of potentiometer accuracy, but a question of just what is meant by the impedance and power factor of an iron-core coil which generates harmonics when a sine wave of current is passed through it.

With reference to Figure 1, suppose that Z_x is an iron-core reactor. The current passed through it is of good wave form, because the resistor R is the chief impedance in the circuit. The voltage drop across Z_x probably will contain conspicuous harmonics. The voltage output from the voltage divider has a very good wave form. Thus, it may be seen that the output voltage from the voltage divider is adjusted actually to equal the fundamental component of voltage drop across Z_x, and the harmonics are eliminated by the filter. Under this condition, the result obtained by dividing the voltmeter reading by N is the rms value of the fundamental component of the impedance drop, and not the rms value of the actual voltage drop. The value of impedance obtained by dividing this voltage drop by the ammeter reading is the fundamental component of impedance. It is interesting to note that the harmonics do not cause any doubt about the wattmeter accuracy, for, even if the harmonics were impressed across the potential coil of the wattmeter, there would be no harmonic current in the current coil, and the reading would be the same.

In Figure 2 suppose that Z_x is a small transformer, the core loss and exciting current of which are to be measured. In this case, the voltage across Z_x is of good wave form, but the current through Z_x will contain pronounced harmonics. When the potentiometer is balanced, the harmonics are again eliminated by the filter, and the value of current determined by the potentiometer is the rms value of the fundamental component of exciting current. The calculated impedance is the fundamental component of impedance. The divided wattmeter reading is the true value of power loss.

Operation at Higher Frequencies

The design of the multiplied-deflection potentiometer is made possible because the dynamometer wattmeter provides isolation between its potential coil and its current coil. Thus, the range of frequency is the same as that of a dynamometer wattmeter. This places the upper limit at about 1,000 cycles. A modified design, which utilizes a thermocouple wattmeter, is being studied, but this calls for major changes in the entire circuit design.

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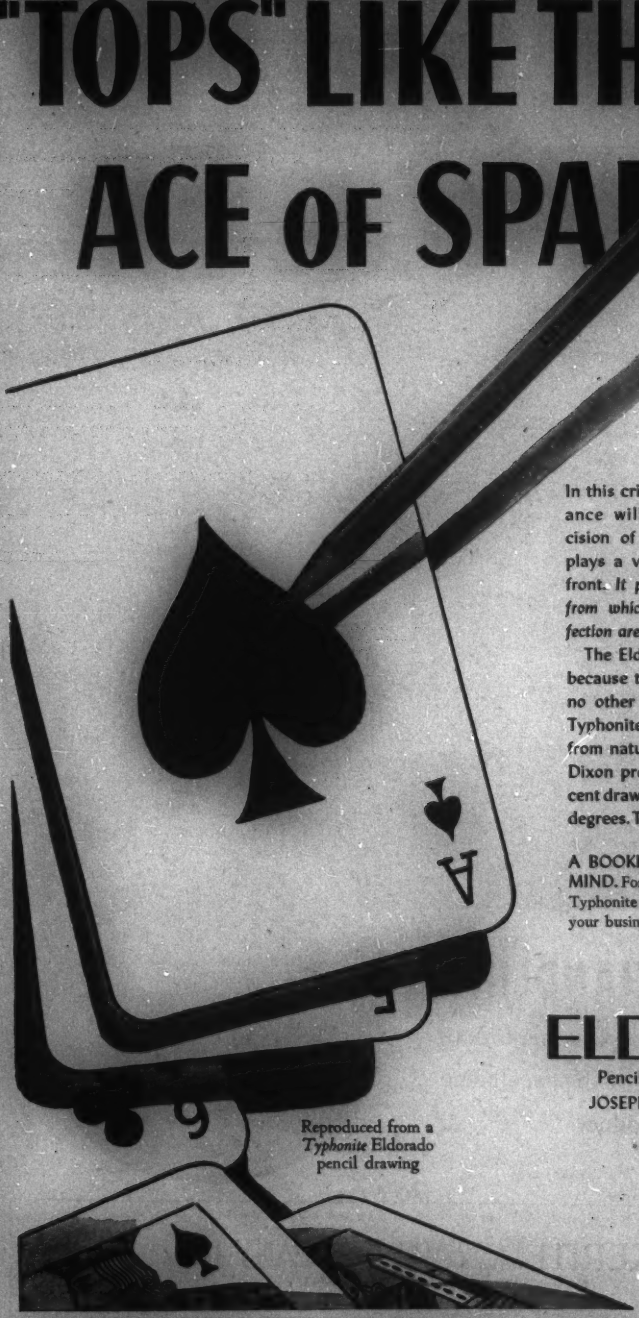

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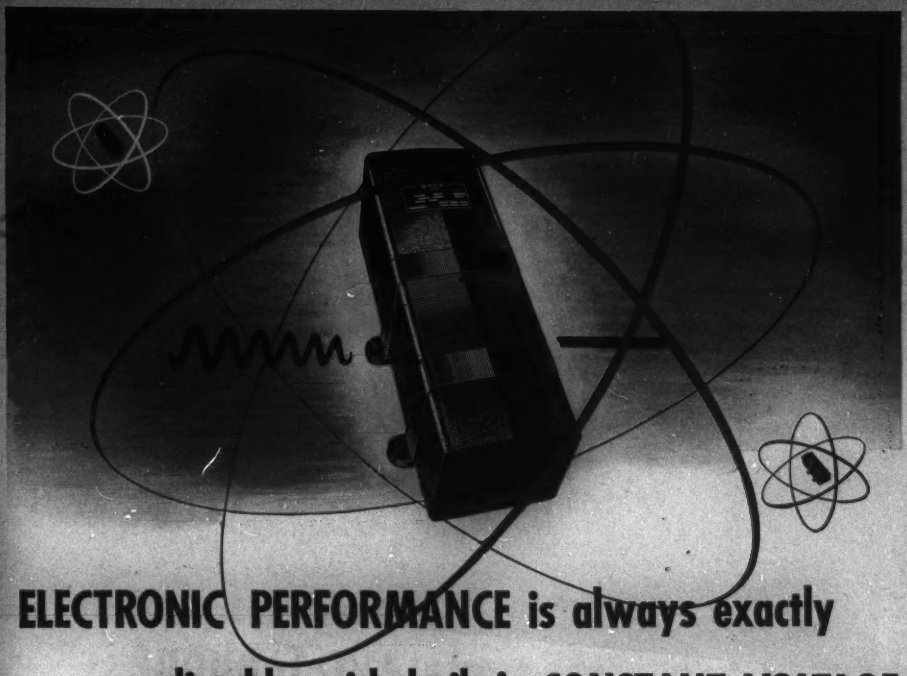

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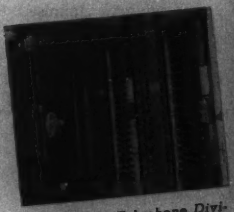

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TELEPHONE DIVISION — An IT&T Associate — Newark, N. J.

New Multiplier Phototube for

VERY LOW LIGHT LEVELS...

SENSITIVITY 3 TIMES THAT OF RCA-931

SIGNALS are amplified up to 200,000 times and more in this new RCA multiplier phototube—over three times the amplification possible with the famous RCA-931—because manufacturing techniques have been improved materially by RCA engineers.

This really amazing sensitivity is made possible by the skillful use of secondary emission as cathode electrons are impelled against 9 successive dynodes before they reach the plate. At each dynode, secondary electrons are produced to multiply the electron current enormously.

Because this high amplification is accomplished within the phototube itself, extremely low light levels will produce high outputs without the high-gain amplifier stages required with conventional phototubes.

HIGH SIGNAL-TO-NOISE RATIO. Because high-gain amplifier stages are unnecessary with the RCA-931-A, sources of extraneous electrical "noise" (such as grid leaks, etc.) are eliminated, and a favorable signal-to-noise ratio can be obtained for very low light levels.

HIGH SENSITIVITY. The 931-A operated at 100 volts per stage has a sensitivity of 2 amperes per lumen; or over 3 times that of the superseded 931 at the same voltage per stage.

CIRCUIT SIMPLICITY. Where light signals are very small and high gain is needed, the 931-A provides a simpler circuit than that for a conventional phototube and its accompanying high-gain amplifier stages; also when the 931-A is used as a d-c amplifier, its zero-reading has excellent stability, and there is no problem of circuit feedback.

COLOR SENSITIVITY. The 931-A—like the 931—employs the S-4 photosurface which is highly sensitive to blue light; peak sensitivity is at about 3750 A°. Frequency response is flat up to a limit determined by transit-time effects, well above 10 million cycles per second. Dark current is very low. Full details are available on request (see coupon).

APPLICATIONS. A typical application of the 931-A is in quantitative spectrographic analysis. The 931-A and its associated circuits are substituted for the photographic plate commonly used in such analyses. This method is speedy, and results can be observed with excellent accuracy. This method of spectrographic analysis is widely used in vitamin measurements.

Cross section of the 931-A, showing electron paths in red.

RCA application engineers will be glad to help you apply the RCA-931-A—or other RCA electron tubes—to the solution of your design problems. Write, outlining your problem, to Commercial Engineering Section, RCA, 587 South Fifth Street, Harrison, N. J.

TECHNICAL DATA. Nine multiplier stages. Cathode photosurface, S-4. Max. seated height, 3¼". Max. diam., 1-5/16". Base, small shell submagnal 11-pin. Mounts in any position.

MAXIMUM RATINGS (Absolute values): Plate volts (d-c or peak a-c), 1250. Volts between dynode No. 9 and anode, 250. Plate current, 2.5 milliamperes. Plate dissipation, 0.5 watt.

CHARACTERISTICS:

Volts per stage	75	100	Volts
Luminous sensitivity	0.3	2.0	μAmp./μLumen
Current amplification	30,000	200,000	
Sensitivity at 3750 Angstroms	270	1800	Amp./Watt

Order through your local RCA Tube and Equipment Distributor or contact Radio Corporation of America, Harrison, New Jersey.

RADIO CORPORATION OF AMERICA

FREE!

(Please check items wanted)

☐ 4-page technical data sheet giving description, ratings, characteristics, typical circuit diagrams, performance curves, and typical circuits for the RCA-931-A.

☐ 16-page booklet entitled "RCA Phototubes," chock-full of valuable tube data, application notes, etc., for RCA phototubes.

RCA, 587 So. Fifth Street, Harrison, N. J.
Gentlemen: Please rush me the items checked above.

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COVERED BY PATENTS 1,797,850, 2,067,577 AND PATENTS PENDING

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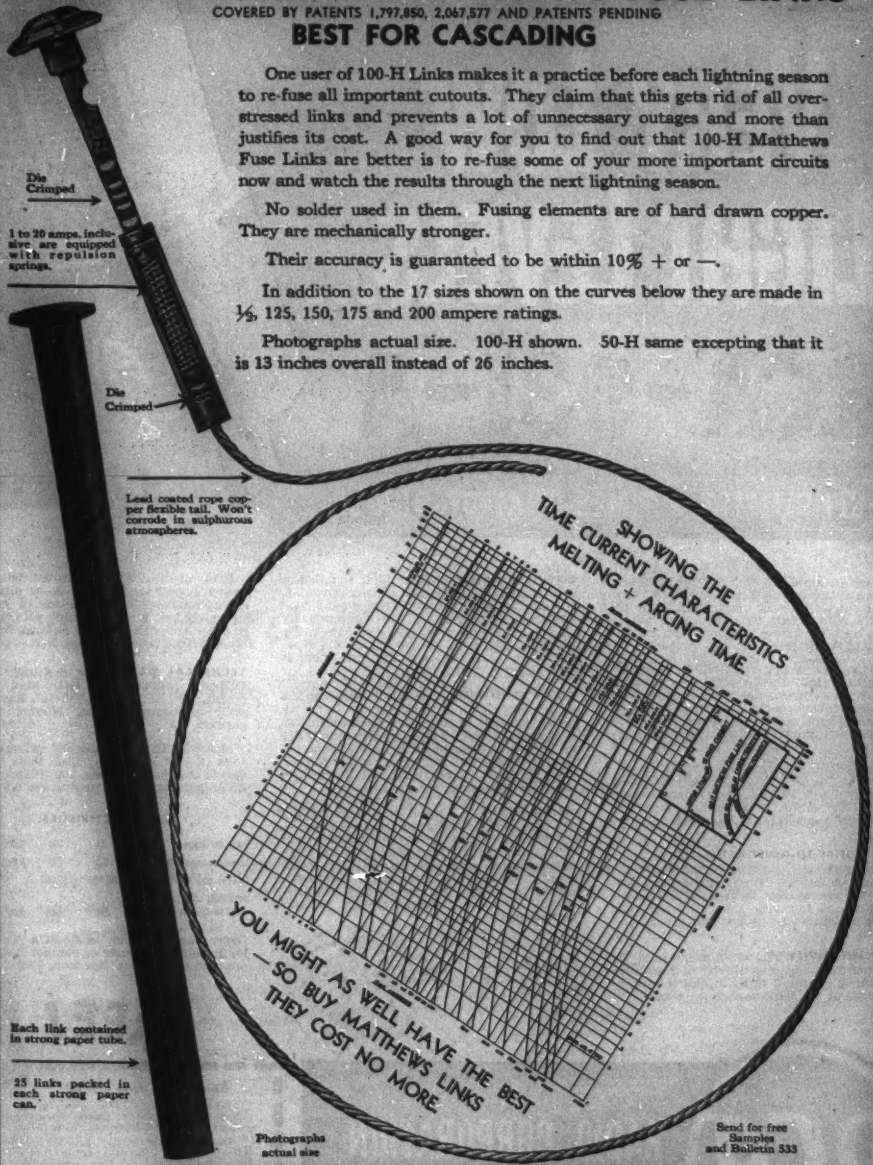
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1 to 20 amps. inclusive are equipped with regulation springs.
Die Crimped
Lead coated rope copper flexible tail. Won't corrode in sulphurous atmospheres.
SHOWING THE TIME CURRENT CHARACTERISTICS MELTING + ARCING TIME.
YOU MIGHT AS WELL HAVE THE BEST —SO BUY MATTHEWS LINKS THEY COST NO MORE.
Each link contained in strong paper tube.
25 links packed in each strong paper can.
Photographs actual size
Send for free Samples and Bulletin 533

One user of 100-H Links makes it a practice before each lightning season to re-fuse all important cutouts. They claim that this gets rid of all over-stressed links and prevents a lot of unnecessary outages and more than justifies its cost. A good way for you to find out that 100-H Matthews Fuse Links are better is to re-fuse some of your more important circuits now and watch the results through the next lightning season.

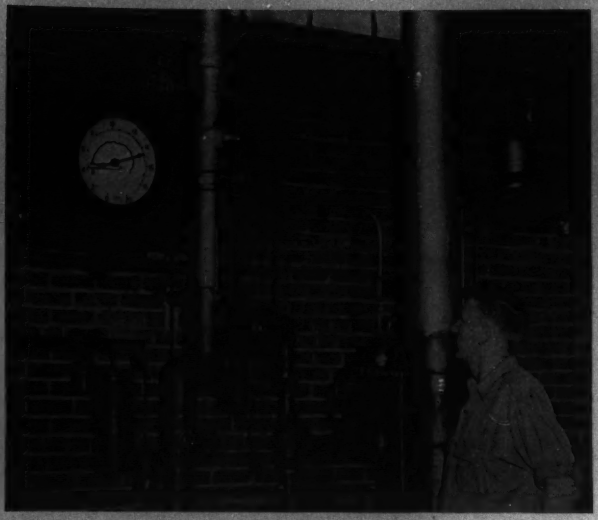
No solder used in them. Fusing elements are of hard drawn copper. They are mechanically stronger.

Their accuracy is guaranteed to be within 10% + or —.

In addition to the 17 sizes shown on the curves below they are made in ½, 125, 150, 175 and 200 ampere ratings.

Photographs actual size. 100-H shown. 50-H same excepting that it is 13 inches overall instead of 26 inches.

W. N. MATTHEWS CORPORATION, ST. LOUIS, U. S. A.



Located high above the floor so that it can be read far down the firing aisle, this Micromax Round-Chart CO_2 Recorder helps a New York State plant to save coal by improving combustion beneath its stoker-fired boilers.

The Strip-Chart form of Micromax CO_2 Recorder is preferred by some users.

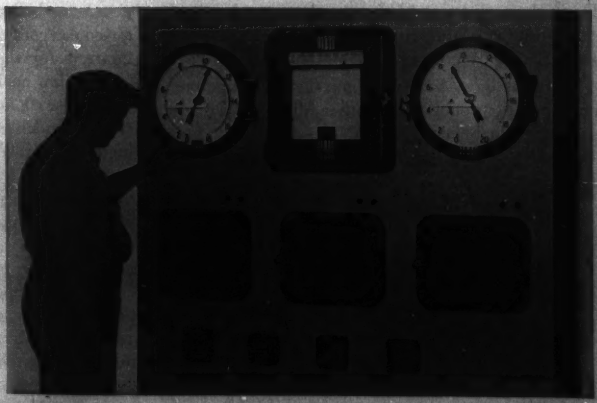
TRYING TO SAVE FUEL?
Maybe a Micromax CO_2 Recorder Can Help

Freed by the Micromax CO_2 Recorder from the job of analyzing flue-gas, at frequent intervals, many a plant engineer is saving fuel simply because he knows more about CO_2—and knows it more quickly—than ever before. For when the Micromax shows the need of a change in air supply to the boiler, the engineer makes the correction with speed; and quickly sees the result on the Recorder's chart. He can tell, from minute to minute if he wishes, just how combustion stands in relation to optimum efficiency. And he has the CO_2 records to help plan future operating savings.

One of the outstanding successes of modern instrumentation has been scored by this Recorder. Coming into the power field when CO_2 recorders were widely regarded as not practical, this instrument was on a "make good if you can" basis in every early installation. Two or three types of CO_2 meters were already available; the arrival of still another didn't rouse much comment—at first.

But the comment came quickly enough after a few installations had been made, because the new device overcame the standard objections to automatic CO_2 meters—it was sensitive, it was not easily damaged in use, and it required practically no servicing. Users checked it, found it accurate; could see for themselves its other qualities; came to depend on it.

Today, wherever any thermal-conductivity-method recorder can be used, these advantages of sensitivity, sturdiness and low maintenance can be enjoyed. If you have a CO_2-analysis problem, one of our engineers will gladly tell you more about Micromax. If you prefer a quick, clear, printed description, ask for Catalog N-91-163.



Micromax Recorders for Flow, Temperature and CO_2, being mounted, together with Metermax Combustion Control, on a boiler-control board before shipment from our plant. These panels arrive ready for connection to boiler, etc.; greatly simplify the installation.

depends on me!
A Slogan For Every American
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LEEDS & NORTHRUP
MEASURING INSTRUMENTS · TELEMETERS · AUTOMATIC CONTROLS · HEAT-TREATING FURNACES

When the lights go on again in Grigoriopol

Three short years ago Grigoriopol was a thriving city of the Russian Ukraine. Today it is a scene of desolation . . . victim of ravaging Hitlerite hordes.

But some day—soon we hope—lights will go on again in Grigoriopol, and in other Allied cities now under the Nazi heel.

When that time comes . . . thanks to a new idea in modern warfare . . . emergency electric power will be available to revitalize industries in war torn cities—immediately after they are retaken from the enemy.

This new idea—a self-contained POWER-TRAIN—has now been made a reality by the engineering brains and skill of Westinghouse.

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Each POWER-TRAIN consists of 8 cars. Ingeniously assembled in these cars are: a 5000 kw steam turbo-generator, boilers, power stokers, boiler feed pumps, air-cooled condensers, auxiliary Diesel engine, living quarters for the crew—even conveyer equipment for handling coal which will be mined locally for fuel.

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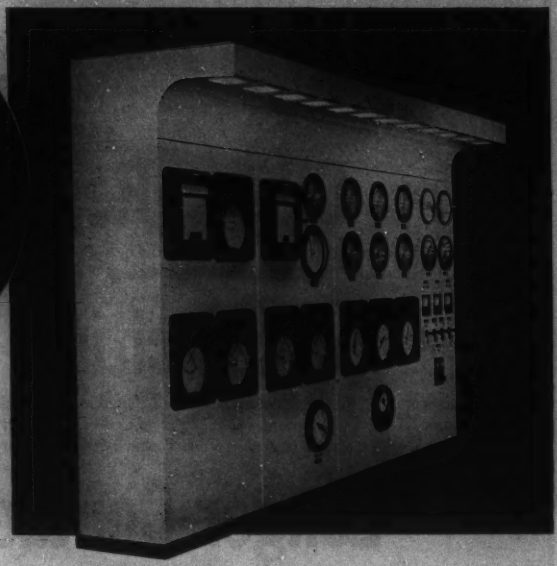

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5/8% Half-Cycling Steps plus "Feather-Touch Control" permits band width settings within ±⅜%. Allis-Chalmers was the first to introduce Feeder Voltage Regulators provided with ⅝% steps.

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Allis-Chalmers 5/8% Step Regulators need only one-third the exciting current required by older type regulators. The step regulator, in effect, releases kva for other purposes... or reduces the burden of the generating system and the primary distribution system.

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4,000,000 kva throughout the country is regulated by Allis-Chalmers equipment... yet there has never been a contact that has had to be replaced due to deterioration under normal operation!

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Exclusive Unit Construction eliminates 78 bolted connections required with conventional terminal board and stud arrangement. Both mechanism and transformer in Allis-Chalmers Step Regulators can be removed or placed into tank *as a unit*... without disconnecting leads or removing terminals!

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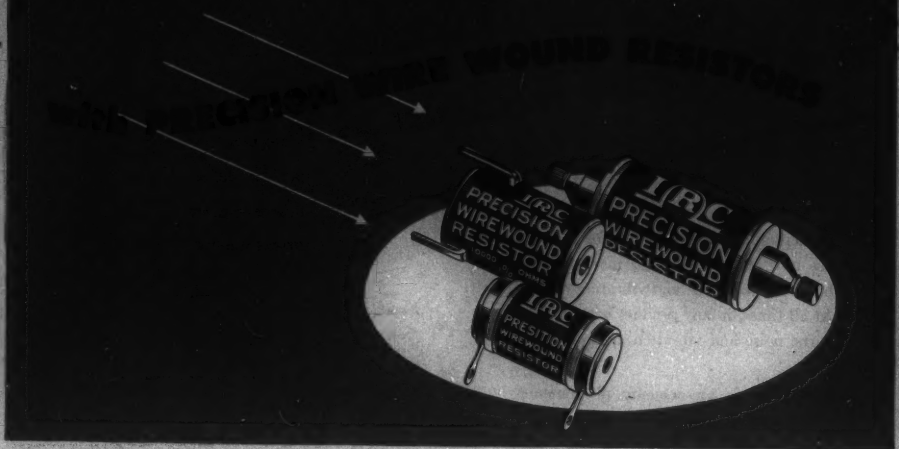

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IRC will be in a specially favorable position to supply *all types* of Resistance units—of high Quality—in large Quantity—at low costs made possible by mass production.

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Produced by the most modern and efficient manufacturing methods, tested and perfected to meet the exacting demands of war, IRC Resistors will maintain their leadership as first choice of electronic engineers, manufacturers and service industries of tomorrow. . . . You are invited to consult our engineering-research staff now, in confidence, on any resistance problems connected with your peacetime products.

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1. *Most rigid specifications on enameled wire.*
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3. *Steatite ceramic (with baked impregnation to prevent moisture absorption and to protect enameled wire from surface abrasions).*
4. *Specially designed winding machines eliminate stress and strain, avert damage to insulation and minimize fatigue of wire.*
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IT'S the Burndy HYTOOL . . . the easy-to-use indenting pliers which *indent* Burndy HYDENT connectors to wires merely by closing the jaws. It makes a small wire electrical connection quicker, *surer and stronger*, than by any other method.

Burndy HYDENT connectors, are *one-piece, pure copper* connectors. Thus, when firmly indented to wires with the HYTOOL, they provide connections of *maximum conductivity*, that are *on to stay!*

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Burndy HYDENT Connectors are available for all wire and cable sizes from #30 to 2500 mcm . . . and in types for all connection problems.

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Whether you rebuild or manufacture electrical units, you will find a wide selection of insulating varnishes in the DOLPH line to meet your exacting requirements.

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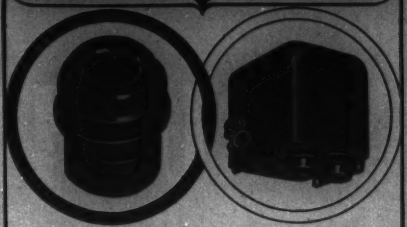

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A.I.E.E. Standards
No. 45A
January 1, 1944

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This new edition of the modification of and supplement to AIEE Standard No. 45 is to apply during the National Emergency only. It must be used in conjunction with the present edition of No. 45 and provides for conservation of critical materials. The price of this 28-page pamphlet, No. 45A, is 50 cents. (50% discount to members of AIEE on single copies.)

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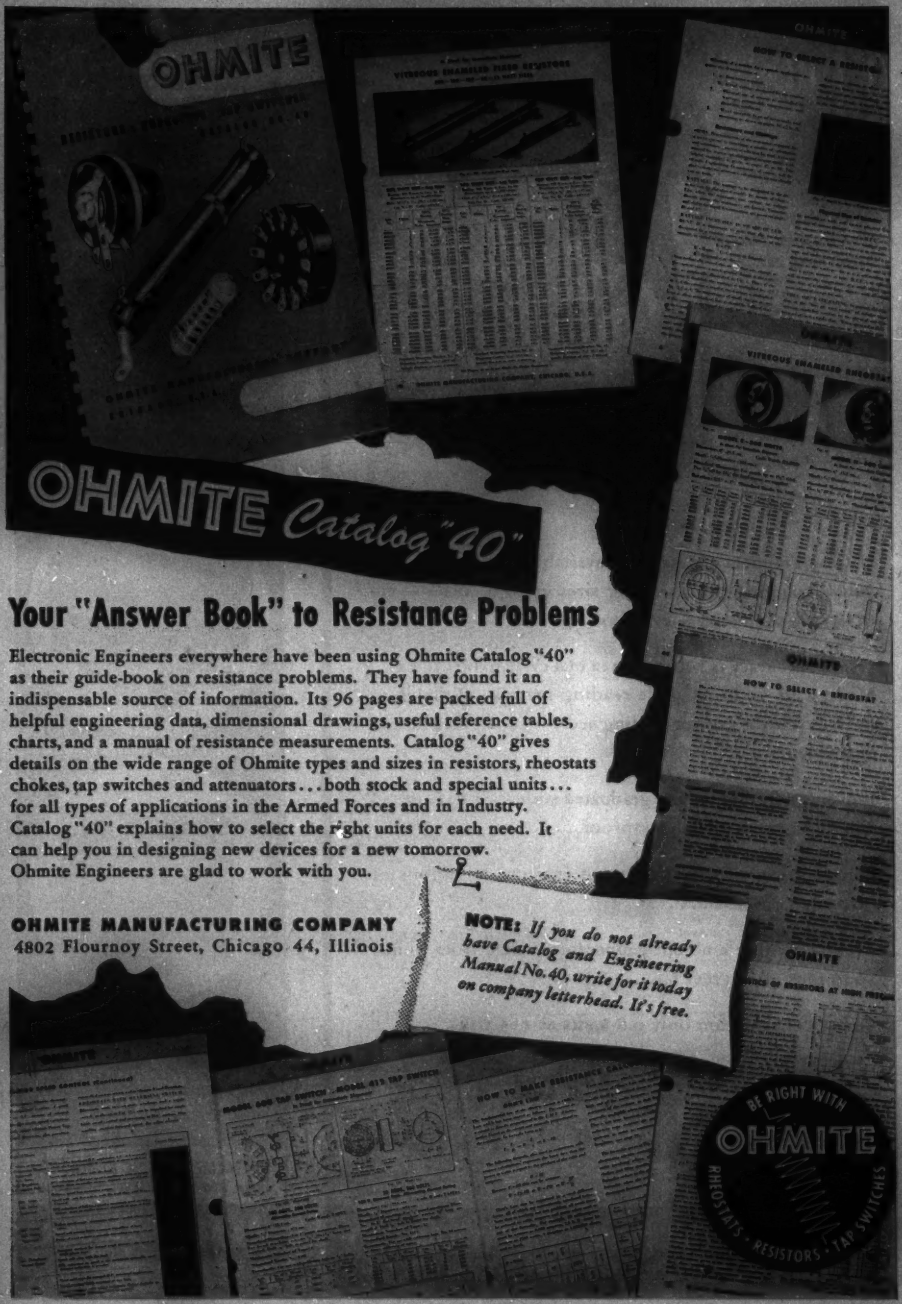
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Indication by pointer and graduated scale, easy to read. . . . Vibration-proof and shock-proof. . . .

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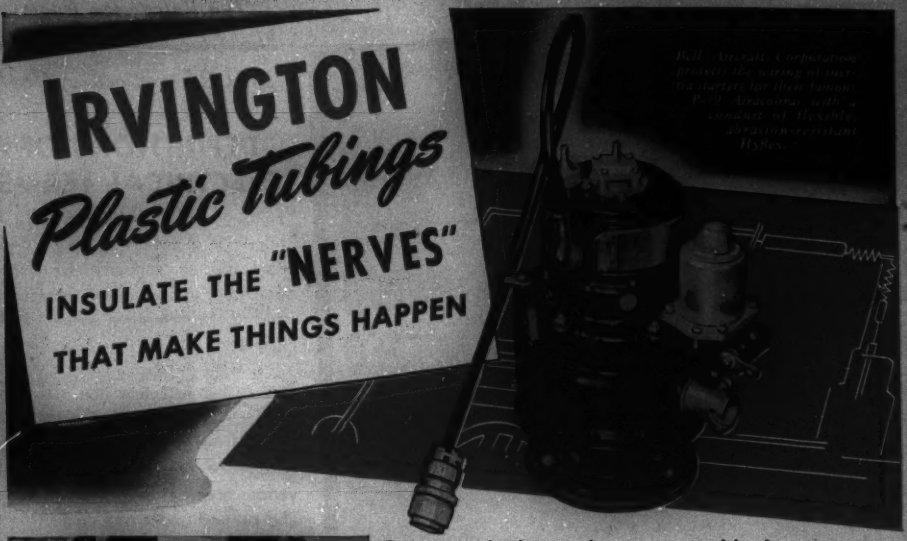

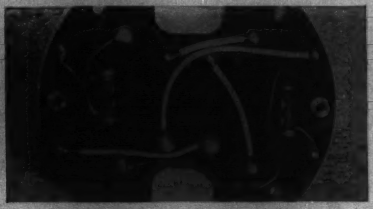

Insulation on soldered wires of this 3½" diameter, temperature indicator is Irv-O-Lite XTE-30. It was specified by the Lewis Engineering Company, Naugatuck, Conn. Note how close the tubing is to the soldered connections.

Transflex is used on the terminals of the main electrical distribution box of Mainliner planes, operated by United Air Lines. Besides insulating the lugs, this transparent tubing permits immediate identification and inspection of the terminals.

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IRV-O-LITE XTE-30 is a good, all-purpose insulation. Wires covered with XTE-30 can be readily soldered.

IRV-O-LITE XTE-130 has unusual oven life. It is unaffected by a temperature of 105 deg. C. for 1,000 consecutive hours.

TRANSFLEX is transparent and resists brittleness at temperatures as low as —58 deg. F.

HYFLEX, similar to Transflex in properties is available in six opaque colors.

IVI-FLEX is rubberlike and resists extremely low temperatures. It withstands a hammer blow at —70 deg. F.

All these tubings are resistant to acids, alkalies, denatured alcohol and petroleum products, including gasoline.

For more information on specific properties of each Irvington Plastic Tubing, send for this catalog. Write Dept. 56

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Although our machines are now devoted to the extrusion of tubing for electrical insulation on war equipment, we are preparing to meet your post-war demands for extruded shapes, rods, and thread. Write us of your requirements.

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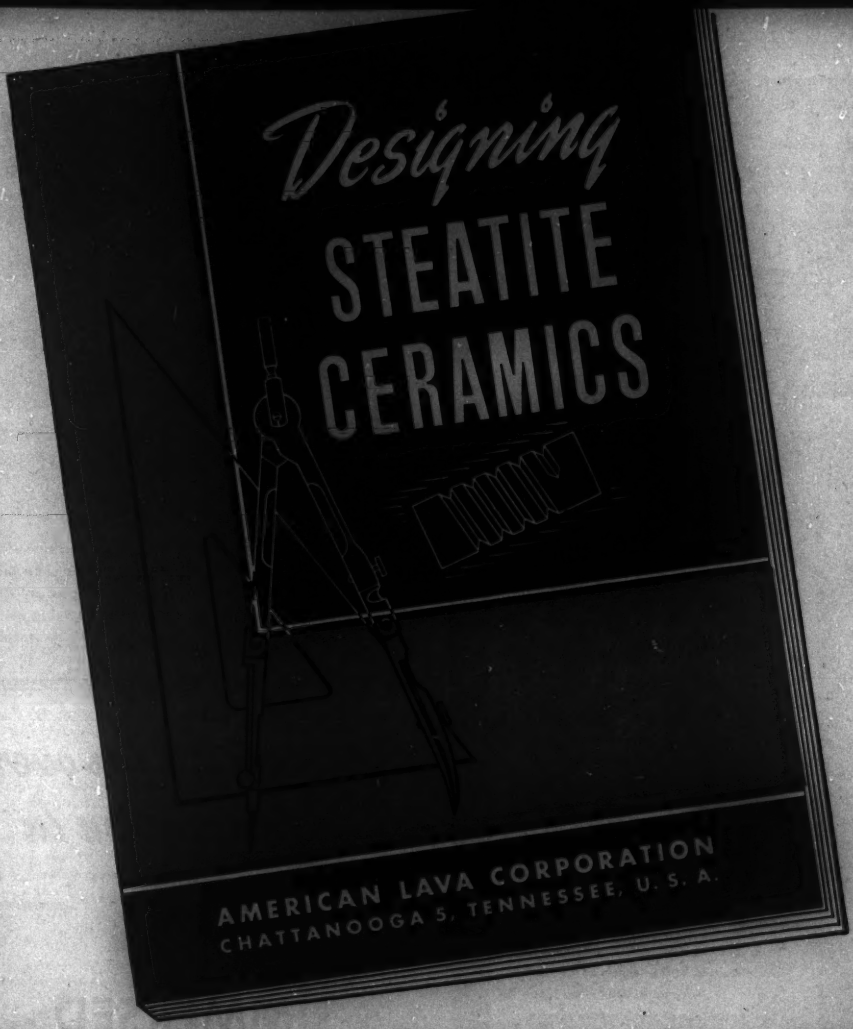

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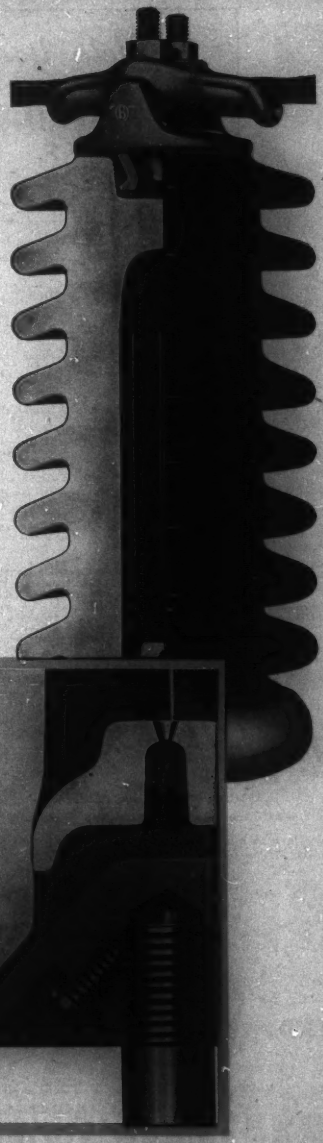

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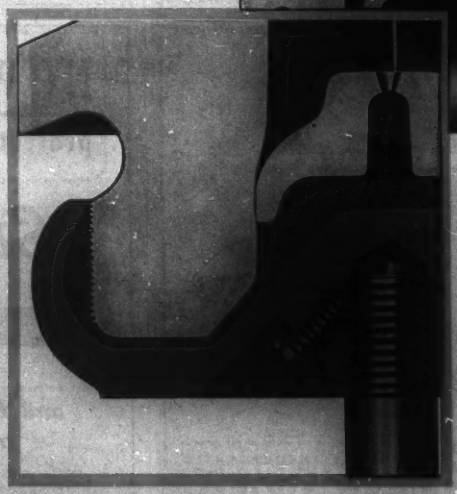

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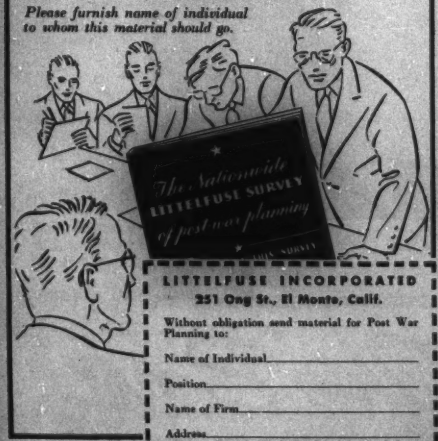

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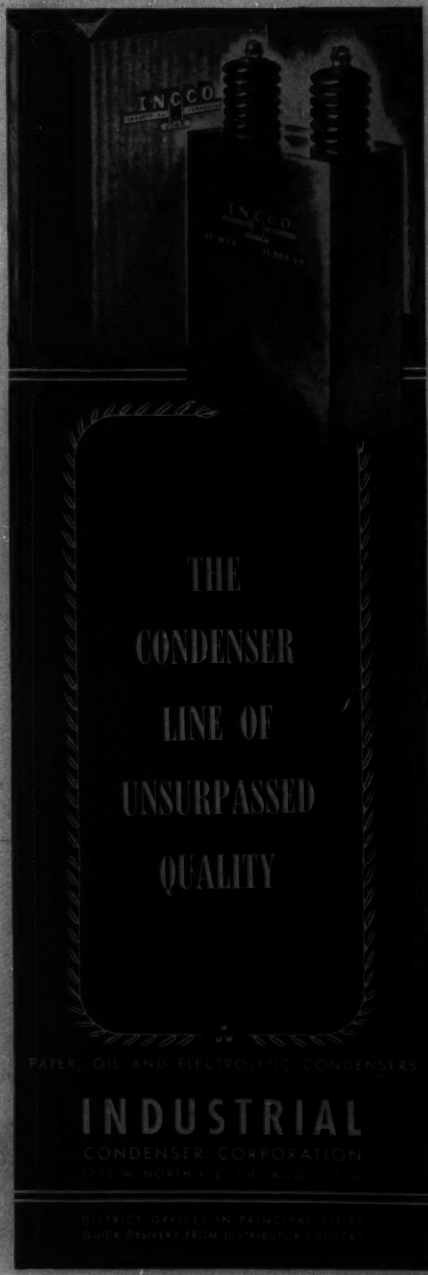

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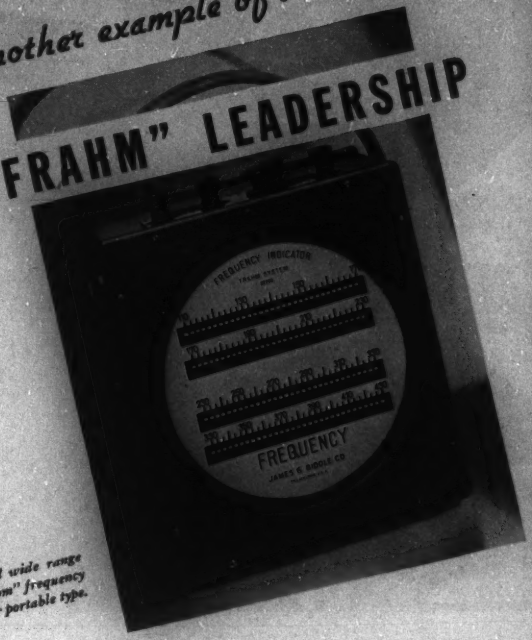

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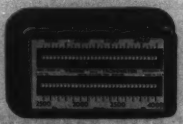

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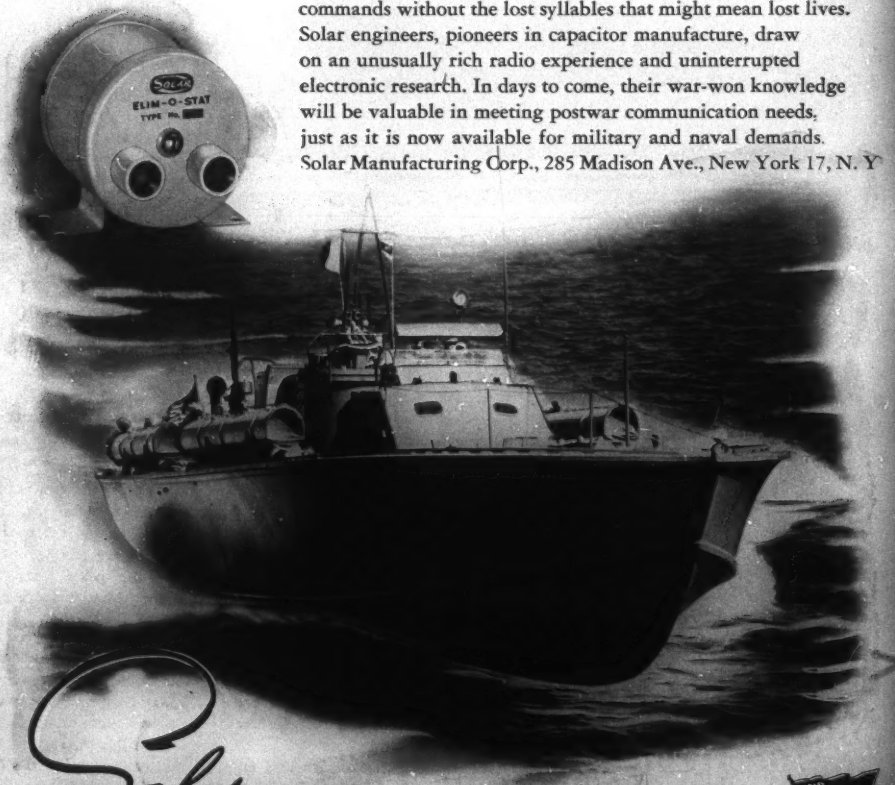

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